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Table 3.2 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in southwest corner of Airbase soil and sediment samples (pg/g [ppt] dry weight), Bien Hoa, Viet Nam, January 2008 and November 2010.

Sample ID	Date	Media	Depth (m bgs)	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
08VNBH071 ¹	16-Jan-08	Soil	0-10	3640	6030	1900	1020	1410	3720	7400	52000	32300	748	152	119	5180	5150	70.7
08VNBH072 ¹	16-Jan-08	Soil	0-10	51.2	65.8	2.36	58.6	261	1170	4.03	47.2	21.2	14.7	52.5	47	56.1	56.2	91.1
10VNBH214	3-Nov-10	Soil	0-20	62.7	87.6	66.2	412	3790	12500	5.58	76.3	50.1	102	256	212	107	110	57.0
10VNBH215	3-Nov-10	Soil	0-10	7.84	13.1	0.376	12.9	102	443	0.682	12.5	49.5	36.3	21.2	NDR 12.1	9.21	9.22	85.0
10VNBH216	3-Nov-10	Soil	0-20	124	136	14.7	70.6	515	2760	2.4	18.2	20.5	22.8	60.9	56.5	130	131	94.7
10VNBH217	3-Nov-10	Soil	0-10	33.8	41.6	12.6	39.6	351	1370	2.23	15.3	20.4	30.9	75.5	80.9	40.9	41.1	82.2
10VNBH218	3-Nov-10	Soil	0-15	25.8	32.4	3.52	35.1	120	489	1.86	25.3	17	9.39	19.6	13.7	30.2	30	86.0
10VNBH219	3-Nov-10	Soil	0-15	21.5	22.6	15.9	208	1520	8150	2.31	20.5	46.1	175	356	341	45.8	47.4	45.4

¹ Archived historical samples from 2008 analyzed during the 2010 program.

² Laboratory QA/QC for 10VNBH219 did not meet accepted criteria for 1,2,3,4,6,7,8-HPCDF. Given that the contribution of this congener to Total TEQ concentration is minimal (TEF = 0.01), results of this analysis were used.

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

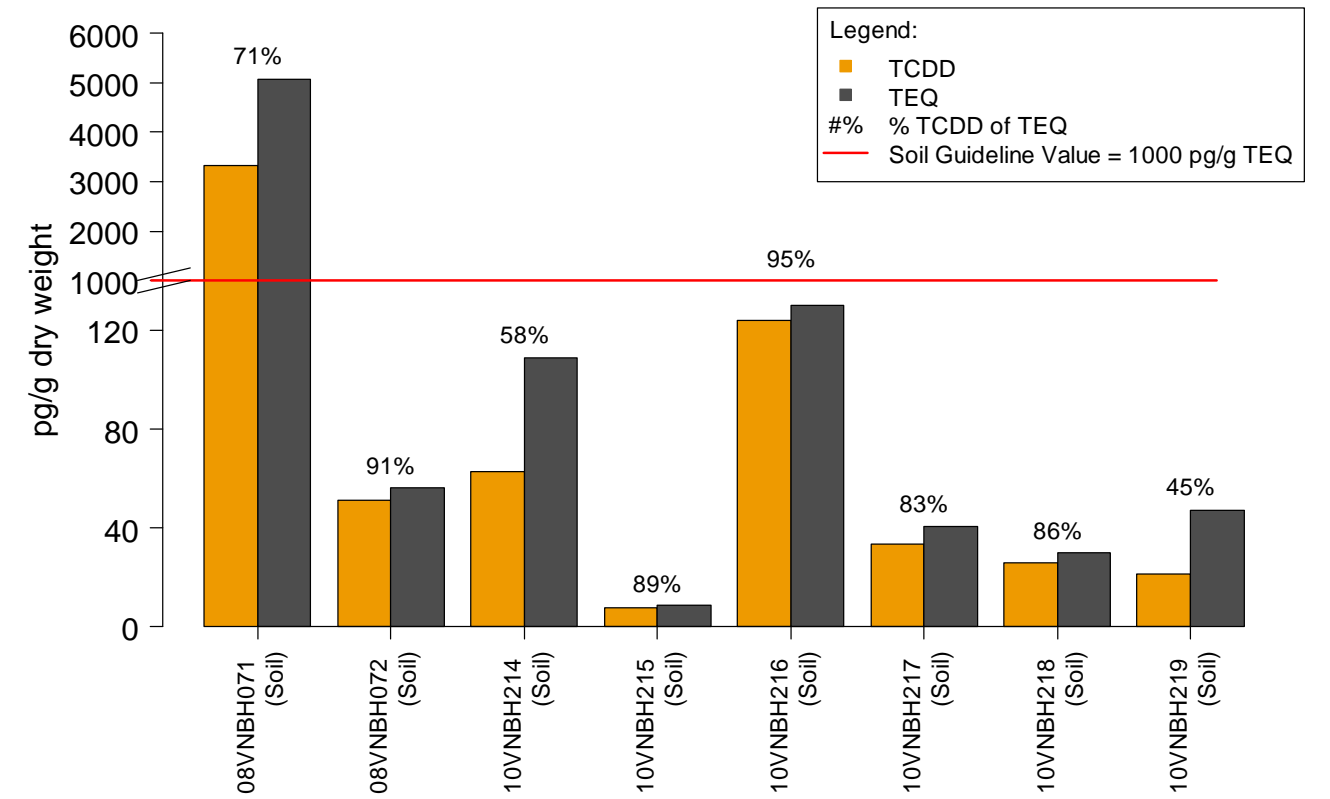
NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

■ Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Figure 3.2 Soil and sediment sampling locations in the southwest corner of Bien Hoa Airbase, Viet Nam, 2008 and 2010.



TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil samples collected from the southwest corner of Airbase, Bien Hoa, Viet Nam, January 2008 and November 2010.



Legend

- Airport Boundary
- Ward Boundary
- Direction of runoff

Soils/Sediment:

2010 (Hatfield/Office 33)	2010 (Hatfield/Office 33)
2008 (Hatfield/VRTC)	2008 (Hatfield/VRTC)

Viet Nam

Hatfield CONSULTANTS

*Vietnamese National Standard for Dioxin TCVN 8183:2009 (1000 ppt Soil, 150 ppt Sediment).

0 0.04 0.08 0.16 Km

Scale: 1:50,198.501

Projection: GCS WGS 1984

Data Sources:

- a) Image acquired from World View 2010
- b) Sampling Locations from Hatfield/VRTC and 10-80
- c) Ward boundaries estimated from: KAP of Local Residents at a Dioxin Hotspot - Bien Hoa - Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008

3.1.3 Z1 Area

Located in the south-central area of Bien Hoa Airbase, the Z1 Area is highly contaminated with dioxin, given that it was the main storage area for Agent Orange, Blue and White herbicides at Bien Hoa during Operation Ranch Hand. During the US - Viet Nam war, large herbicide storage tanks were present at this site, and the area surrounding the Z1 Area was subject to significant spillage. Major spills occurred in the environment in this area at least four times between December 1969 and March 1970; approximately 25,000 litres of Agent Orange and 2,500 Agent White were released to the Environment (US DOD 2007).

This site has recently been remediated by MND, including construction of drainage ditches and containment of contaminated soils in a secure landfill; the remediation program covers an area of approximately 43,000 m². Downstream canals from the Ranch Hand herbicide storage tank area receive drainage from the hotspot site, and there are a number of ponds and lakes used by local fishermen (including Z1 Lake). The area has changed significantly since the implementation of remediation efforts. Rainwater from the storage area now flows to the Dong Nai River via newly constructed drainage canals, instead of Bien Hung Lake and other lakes inside the Airbase.

A number of soil samples were collected from the north and south of the Z1 containment area to identify any potential contaminant pathways leading to the general population in Bien Hoa City. Two (2) archived samples from the 2008 sampling program were also analysed by AXYS in 2010. Sampling results are presented in Table 3.3.

Most soil samples collected at the Z1 Area in 2010 had low TEQ concentrations ranging from 1.46 ppt to 212 ppt. Two samples exhibited high TCDD and TEQ concentrations; sample 10VNBH242 had 3,130 ppt TCDD and 3,210 ppt TEQ; 10VNBH243 contained 2,540 ppt TCDD and 2,650 TEQ. Sample 08VNBH167 (collected in 2008) also had elevated TCDD (985 ppt) and TEQ (1,000 ppt) concentrations. Proportions of TCDD to the TEQ concentration in all three samples were above 95%, indicating residual Agent Orange contamination at these sites.

Core samples were collected from the Z1 Area at two locations in 30 cm increments to a depth of 150 cm. Core sample 10VNBH245 and 10VNBH246 were collected to the south and southeast of the landfill area. Results of sample 10VNBH245 demonstrate that TCDD concentrations generally decreased with depth: the TCDD concentration was 7.66 ppt in the 0-30 cm fraction; and non-detectable at 60-90 cm. Non-detectable TCDD concentrations were also observed in soil samples analysed at 60-90 cm and 120-150 cm layers at site 10VNBH246. Results of the core samples remain inconclusive, as samples from several consecutive layers were not analyzed in 2010.

Table 3.3 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in Z1 Area soil and sediment samples (pg/g [ppt] dry weight), Bien Hoa Airbase, Viet Nam, January 2008 and November 2010.

Sample ID	Date	Media	Depth (m bgs)	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2 DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
08VNBH138 ¹	18-Jan-08	Soil	0-10	19.6	19.6	1.61	9.44	51.5	477	1.62	2	7.25	< 0.971	6.33	10.7	22.4	22.4	87.5
08VNBH167 ¹	19-Jan-08	Soil	0-10	985	1050	65.6	128	242	921	33.9	212	199	49.1	39	24.4	1000	1000	98.5
10VNBH241	5-Nov-10	Soil	0-15	196	221	37.1	135	582	2060	10.1	61	94	66.9	75.3	37.2	212	212	92.5
10VNBH242	5-Nov-10	Soil	0-15	3130	3380	221	152	62	215	125	765	758	78.3	9.55	NDR 10.8	3210	3210	97.5
10VNBH243	5-Nov-10	Soil	0-15	2540	2870	298	188	110	450	133	901	745	45.2	25.4	19	2660	2650	95.8
10VNBH244	5-Nov-10	Soil	0-15	74.9	100	29.2	36.7	30.6	133	9.29	61.7	42.2	4.59	2.34	4.21	88.1	88	85.1
10VNBH245-1	5-Nov-10	Soil	0-30	7.66	10.8	2.86	7.02	18.3	67.4	<0.929	7.75	3.69	< 0.929	1.45	1.96	9.83	9.75	78.6
10VNBH245-3	5-Nov-10	Soil	60-90	< 0.921	< 0.921	< 0.921	< 0.921	< 0.921	10.9	< 0.921	< 0.921	< 0.921	< 0.921	< 0.921	< 0.921	1.56	1.46	NC
10VNBH246-3	6-Nov-10	Soil	60-90	NDR 1.69	< 0.963	< 0.963	< 0.963	2.38	17.8	< 0.963	3.28	< 0.963	< 0.963	< 0.963	< 0.963	1.63	1.53	NC
10VNBH246-5	6-Nov-10	Soil	120-150	< 0.986	< 0.986	< 0.986	< 0.986	< 0.986	14.9	< 0.986	3.8	2.23	< 0.986	< 0.986	< 0.986	1.67	1.56	NC
10VNBH247	6-Nov-10	Soil	0-10	93.7	100	21.1	126	858	4340	3.25	18.9	34.4	93.3	261	247	112	113	82.9
10VNBH248	6-Nov-10	Soil	0-10	4.83	5.8	< 0.923	2.67	30.2	162	<0.923	< 0.923	1.86	1.14	< 0.923	6.17	6.31	6.24	77.4
10VNBH250	6-Nov-10	Soil	0-10	28.3	38.8	5.94	81.9	306	1490	2.22	40.9	30.5	45.8	69.9	50.1	34.9	34.8	81.3
10VNBH251	6-Nov-10	Soil	0-10	225	241	26.9	78.8	482	2010	5.51	48.9	33.6	45.5	61.8	42.2	237	237	94.9
10VNBH426	6-Nov-10	Sediment	0-5	111	116	16.2	136	896	3470	5.19	49	24.8	45.3	82.4	58.7	124	125	88.8
10VNBH427	6-Nov-10	Sediment	0-5	212	224	12.9	66.2	393	1770	6.88	35.1	50.8	22.9	44.4	80.1	219	219	96.8
10VNBH428	6-Nov-10	Sediment	0-20	33.9	33.9	5.35	14.2	82.3	342	2.92	6.02	< 2.54	13.4	9.48	14.4	40	39.8	85.2

¹ Archived historical samples from 2008 analyzed during the 2010 program.

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Red shading indicates value exceeds Vietnamese guideline - 150 pg/g TEQ in sediment (TCVN 8183:2009).

Sediment samples were collected from a canal that drains the South Base Lake, a wetland situated to the southeast of the landfill, and Z1 Lake. The sediment sample collected from the wetland area (10VNBH427) south of the Z1 Area had a high TCDD concentration of 212 ppt and TEQ concentration of 219 ppt (96.8% TCDD of TEQ), and exceeded the sediment guideline of 150 ppt TEQ. The sample collected from the canal draining South Base Lake (10VNBH426) also exhibited elevated dioxin levels (111 ppt TCDD; 125 ppt TEQ; 88.8% TCDD of TEQ). The Z1 Lake sediment sample contained relatively low TCDD (33.9 ppt) and TEQ (39.8 ppt) concentrations.

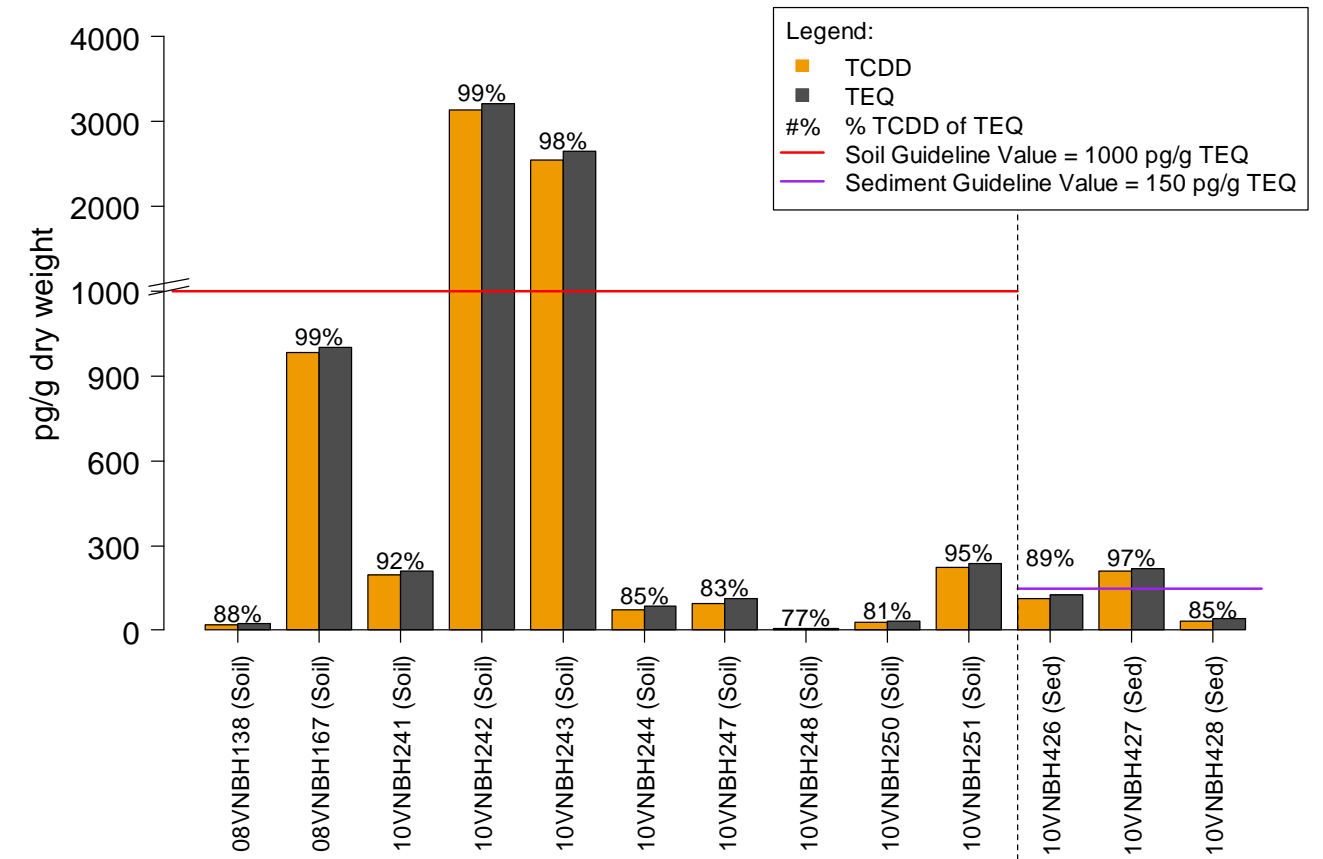
In general, the Hatfield/VRTC (2009) study found that samples collected from the area to the south and southwest of the Z1-contaminated area had higher levels of dioxin than samples collected from the area east and north of the landfill (Figure 3.3). This observation held true for the results of the 2010 study as well.

Construction of the landfill appears to have been effective in significantly reducing the soil dioxin levels in the Z1 Area. However, high levels detected in some soil and sediment samples collected downstream of the Z1 Area in 2010 emphasize the need for periodic monitoring of dioxin levels to confirm the effectiveness of treatment mechanisms, and to prevent the spread of toxic chemicals into the receiving environment (i.e., to fish ponds downstream of the Z1 Area).

Figure 3.3 Soil and sediment sampling locations in the Z1 Area, Bien Hoa Airbase, Viet Nam, 2004 to 2010.



TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil and sediment samples collected from the Z1 Area, Bien Hoa Airbase, Viet Nam, January 2008 and November 2010.



Legend

- Airport Boundary
- Ward Boundary
- Landfill
- Direction of runoff

Soils/Sediment:

Soil and Sediment concentrations exceed Vietnamese National Standard.*

- 2010 (Hatfield/Office 33)
- 2008 (Hatfield/ VRTC)
- 2004/2005 (Hatfield/ 10-80)

Soil and Sediment concentrations below Vietnamese National Standard.*

- 2010 (Hatfield/Office 33)
- 2008 (Hatfield/ VRTC)
- 2004/2005 (Hatfield/ 10-80)

Viet Nam

Hatfield CONSULTANTS

*Vietnamese National Standard for Dioxin TCVN 8183:2009 (1000 ppt Soil, 150 ppt Sediment).

Scale: 1:5,500
Projection: WGS 1984 UTM Zone 48N

Data Sources:
a) Image acquired from World View 2010
b) Sampling Locations from Hatfield/ VRTC and 10-80
c) Ward boundaries estimated from: KAP of Local Residents at a Dioxin Hotspot - Bien Hoa - Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008

3.1.4 Northeastern Perimeter

The northeastern perimeter of the Airbase was sampled in 2010 as a result of slightly elevated dioxin levels (425 ppt TEQ in soil) discovered outside the Airbase during the Hatfield/10-80 (2006) study. During the 2004-2005 sampling program, soil and sediment samples were collected from outside the northeastern perimeter, suggesting potential contamination in the eastern region of the Airbase. This area was not sampled during the Hatfield/VRTC (2009) program. In 2010, the project team sampled this area for the first time, inside the eastern Airbase perimeter, to identify potential contamination sources inside the Airbase.

Eight soil samples and three sediment samples were analyzed in the northeastern part of the Airbase, along the southeastern and eastern sides of the runway, in November 2010. Analytical results are presented in Table 3.4.

One surface soil sample (10VNBH208) collected from a low-lying grass field near the 'NE Perimeter Lake 1' (Figure 3.4) exhibited a TCDD concentration of 996 ppt and a TEQ of 1,040 ppt, slightly exceeding the Vietnamese soil dioxin guideline (1,000 ppt). Another sample collected from the perimeter (10VNBH204) also exhibited slightly elevated TCDD (333 ppt) and TEQ (347 ppt) concentrations. In both of these samples, TCDD contributed to over 95% of the TEQ, indicating Agent Orange as the source of contamination. Dioxin concentrations were lower in the remaining soil samples collected from this area; TCDD concentrations ranged from 3.4 to 47.9 ppt, and TEQ concentrations ranged from 12.1 to 56.1 ppt.

Three (3) sediment samples were collected from an aquaculture pond ('Mr. San Lake'), and 'NE Perimeter Lake 1 and 2' located near the southeastern end of the runway. The sample collected from 'NE Perimeter Lake 1' (10VNBH410) exhibited a TCDD concentration of 600 ppt and a TEQ of 633 ppt, exceeding the Vietnamese sediment dioxin guideline of 150 ppt TEQ. In the remaining two samples, TCDD concentrations were very low (5.11 ppt in 'Mr. San Lake' and 11.6 ppt in 'NE Perimeter Lake 2'), as were TEQs (6 ppt in 'Mr. San Lake' and 12.3 ppt in 'NE Perimeter Lake 2'). Dioxin levels are likely not a significant concern in these latter 2 lakes.

Soil and sediment samples were collected from outside the northeastern Airbase perimeter during the Hatfield/10-80 2004-2005 study (Hatfield/10-80 2006) (Table 1.2). Both soil and sediment samples showed elevated TCDD and TEQ concentrations, but none exceeded the current Vietnamese guidelines for dioxins in soil and sediment. The highest soil TCDD concentration was recorded at 05VN089 (392 ppt), with a resulting TEQ of 424 ppt (92% TCDD of TEQ). The highest sediment dioxin value was recorded in 05VN088 (82.8 ppt TCDD and 101 ppt TEQ). In all the historic samples collected from this area, over 82% of the TEQ was TCDD, indicating Agent Orange as the likely source of contamination.

Table 3.4 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in northeastern Airbase perimeter soil and sediment samples (pg/g [ppt] dry weight), Bien Hoa Airbase, Viet Nam, November 2010.

Sample ID	Date	Media	Depth (m bgs)	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
10VNBH204	2-Nov-10	Soil	0-15	333	376	38.1	69	360	2600	13.8	109	107	43.2	63	91.4	347	347	96.0
10VNBH205	2-Nov-10	Soil	0-20	39.2	71.6	23.2	64.1	286	1500	2.71	43.5	39	49.7	55	56.2	48.4	48.5	80.8
10VNBH206	3-Nov-10	Soil	0-20	32.7	40.3	11.9	48.3	219	926	1.59	14.8	17.7	30.3	46.8	37.2	36.6	36.6	89.3
10VNBH208	3-Nov-10	Soil	0-10	996	1190	136	132	256	1010	85.3	481	474	111	65.5	48.3	1040	1040	95.8
10VNBH209	3-Nov-10	Soil	0-20	17	17.8	3.71	21.9	101	600	0.668	7.27	8.13	10.3	14.5	12.4	19	19.1	89.0
10VNBH210	3-Nov-10	Soil	0-20	3.4	10.2	11.6	73.6	403	2340	0.558	13.6	29.4	95.8	75.6	55.7	11.6	12.1	28.1
10VNBH212	3-Nov-10	Soil	0-20	47.9	56.5	19.2	68.7	294	1240	9.49	33.3	34.1	35.8	54	44.4	56.1	56.1	85.4
10VNBH213	3-Nov-10	Soil	0-20	17.8	20.6	3.74	7.73	21.6	112	1.1	10.5	5.28	2.64	2.8	2.75	18.7	18.7	95.2
10VNBH408	2-Nov-10	Sediment	0-20	11.6	13.2	2.23	1.29	5.65	34.4	1.04	6.71	3.91	1.12	0.506	0.989	12.3	12.3	94.3
10VNBH410	3-Nov-10	Sediment	0-5	600	709	92.1	147	411	1930	96.6	357	289	83	64.8	56.8	634	633	94.8
10VNBH412	3-Nov-10	Sediment	0-120	5.11	7.67	2.17	5.83	49.8	315	0.558	5.29	3.77	5.32	8.94	6.64	5.94	6	85.2

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

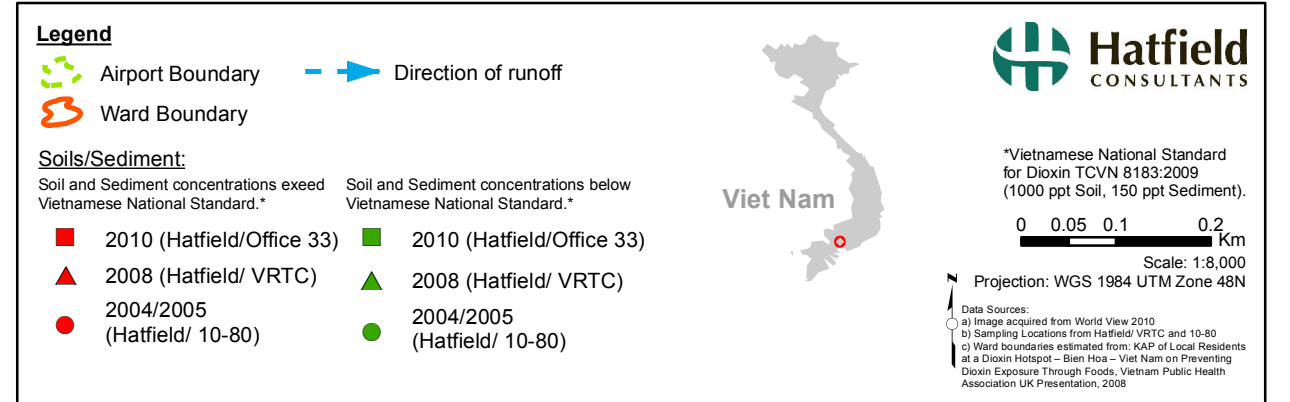
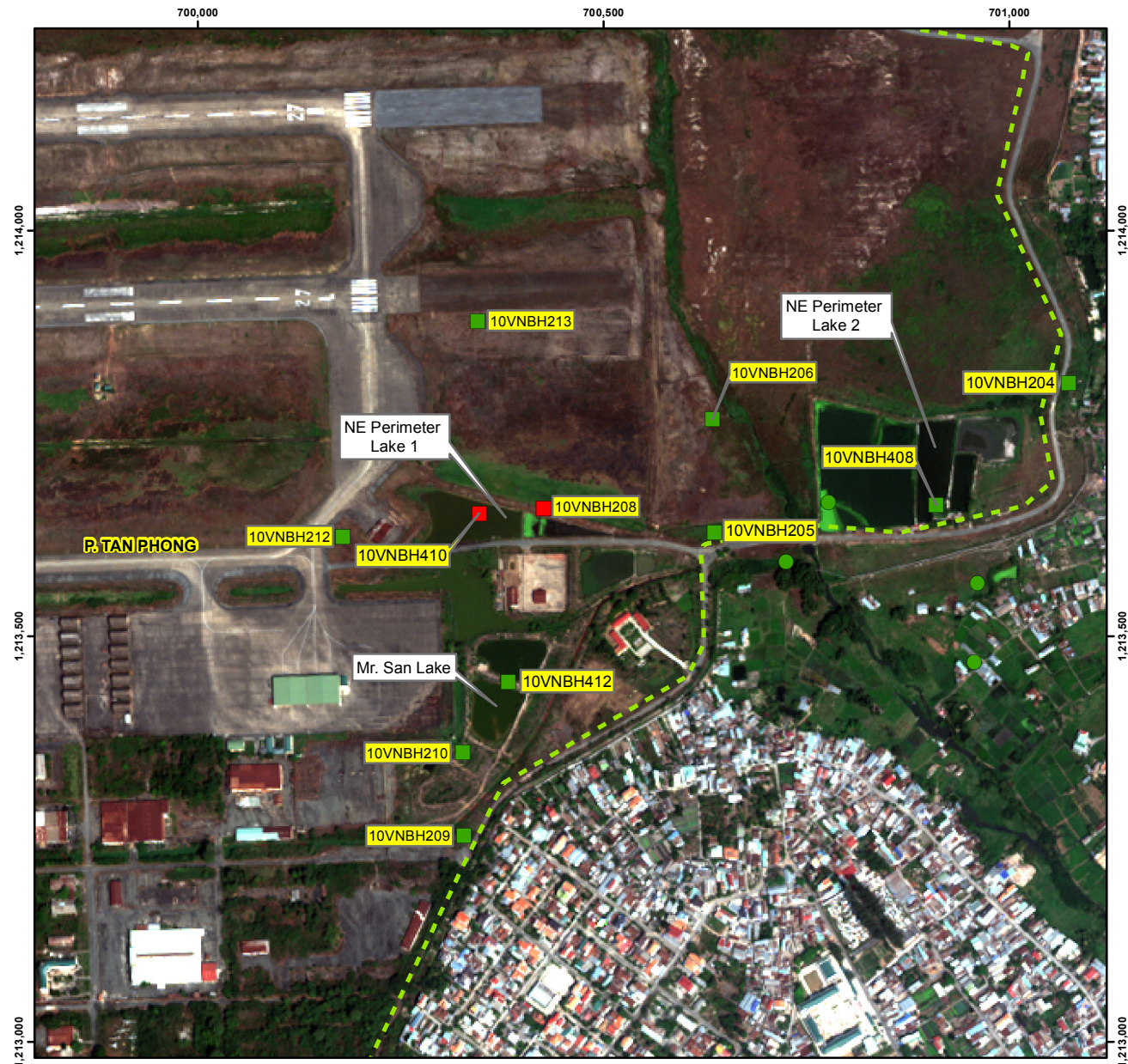
ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

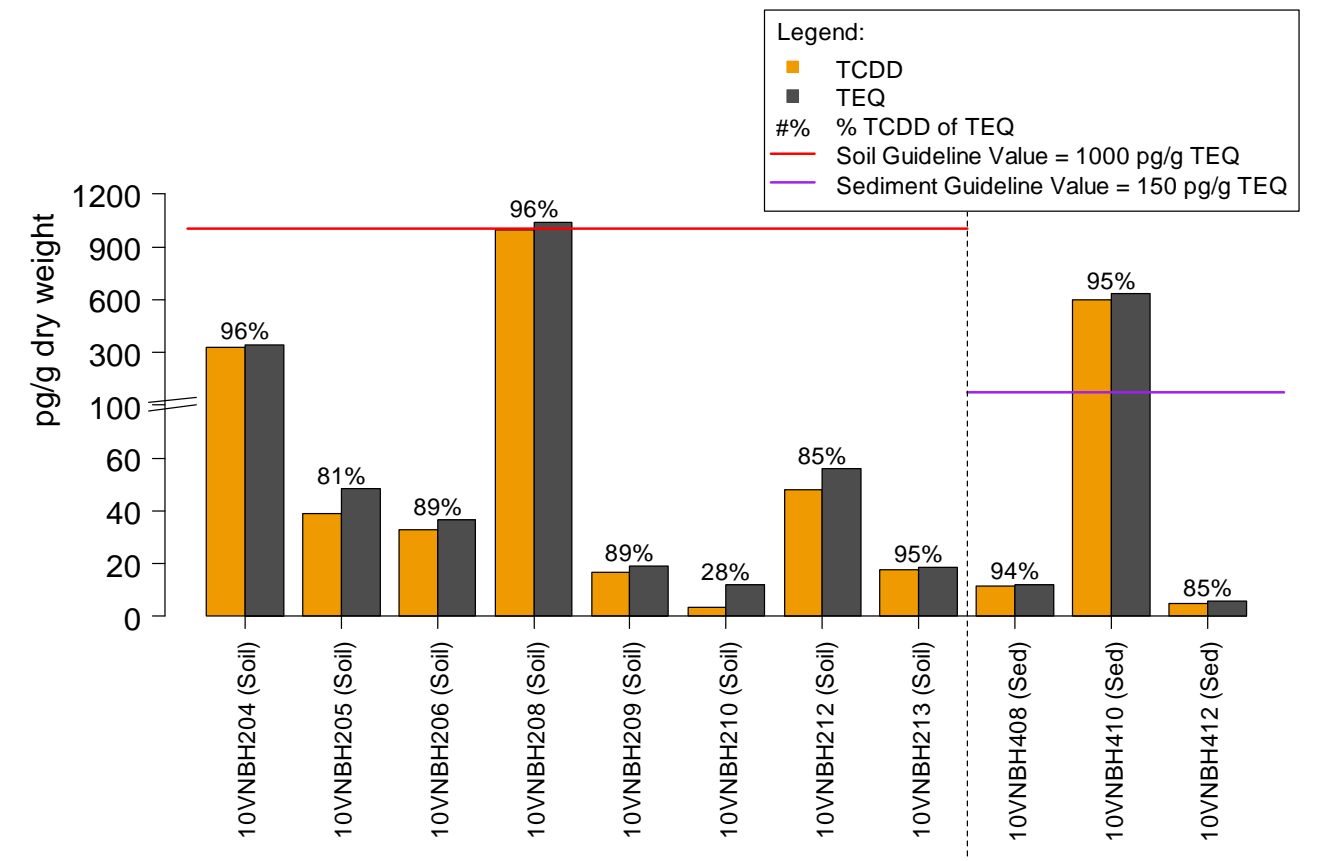
Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Red shading indicates value exceeds Vietnamese guideline - 150 pg/g TEQ in sediment (TCVN 8183:2009).

Figure 3.4 Soil and sediment sampling locations in the northeastern perimeter of Bien Hoa Airbase, Viet Nam, 2004 to 2010.



TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil and sediment samples collected from northeastern perimeter of Airbase, Bien Hoa, Viet Nam, November 2010.



3.1.5 Northern Perimeter and Bien Hoa City (Southern Perimeter)

Four (4) soil and five (5) sediment samples were collected in November 2010 from the northern perimeter of Bien Hoa Airbase, and two (2) sediment samples were collected from outside the southern perimeter, in Bien Hoa City. The northern perimeter was not sampled during previous Hatfield/10-80/VRTC field programs.

Soil samples collected from the north Airbase exhibited low dioxin concentrations; none exceeded the Vietnamese guideline value for dioxins in soil (1000 ppt TEQ). One sample exhibited elevated levels (425 ppt TCDD; 459 ppt TEQ; and 92.6% TCDD of TEQ). In the remaining three samples, TEQ concentrations ranged from 8.47 to 17.1 ppt.

Sediment samples were collected from five (5) sites along the northern perimeter. Two samples exhibited TEQ concentrations exceeding the Vietnamese guideline value for dioxins in sediment (150 ppt TEQ). A sample collected from a small pond on the northwestern perimeter of the Airbase (10VNBH402) exhibited a sediment TCDD concentration of 362 ppt and a TEQ of 372 ppt; this was the highest value recorded in this area. TCDD contributed 97.3% of the TEQ, indicating Agent Orange as the source of contamination. Another sediment sample taken from 'Mr. Binh Lake' (10VNBH406) on the eastern side of the Airbase perimeter also exhibited a high dioxin concentration (257 ppt TCDD; 268 ppt TEQ; 95.9% TCDD of TEQ).

A sediment sample (10VNBH400) collected from a small pond on the northwestern perimeter of the Airbase exhibited slightly elevated dioxin levels (62.8 ppt TCDD; 68.5 ppt TEQ; 91.7% TCDD of TEQ). Elevated dioxin levels observed in this sample, as well as sample 10VNBH402 discussed above, may be attributed to their proximity to the highly contaminated Pacer Ivy Area, the site of former herbicide storage and re-drumming (see Section 3.1.1).

Sediment samples collected from a small pond to the west of 'Mr. Binh Lake' (10VNBH403) and 'Mr. Quy Lake' (10VNBH404) exhibited relatively low TCDD and TEQ concentrations (38.2 ppt TEQ and 5.66 ppt TEQ, respectively).

Two sediment samples were collected from 'Gate 2 Lake' and Bien Hung Lake, located to the south of the Airbase in Bien Hoa City. The sample collected from 'Gate 2 Lake' (10VNBH429) had a relatively low dioxin concentration (24.3 ppt TCDD; 26.9 ppt TEQ; and 90.3% TCDD of TEQ). Elevated dioxin levels were observed in Bien Hung Lake (10VNBH430); the TCDD concentration was 79.1 ppt and TEQ was 95.6 ppt (82.7% TCDD of TEQ).

Bien Hung Lake was sampled at several locations during the 2004-2005 Hatfield/10-80 (2006) field program as well. The historic samples also exhibited elevated dioxin levels (Table 1.2; Figure 1.2). The TEQ levels in sediments from this lake ranged from 36 ppt (86% TCDD to TEQ) to 131 ppt (73% TCDD to TEQ). All the samples analysed thus far from Bien Hung Lake, however, remained below the Vietnamese guideline for sediment dioxins (150 ppt TEQ). Schecter et al. (2001) also reported sediment dioxin in Bien Hung Lake 1 and Bien Hung Lake 2; 177 ppt TCDD was reported as the highest value from both lakes. There is no information in their publication as to the exact location of these lakes or of the samples collected.

Table 3.5 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in northern perimeter of Airbase and Bien Hoa City soil and sediment samples (pg/g [ppt] dry weight), Viet Nam, November 2010.

Sample ID	Date	Media	Depth (m bgs)	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF			
<i>Northern Perimeter</i>																		
10VNBH200	2-Nov-10	Soil	0-15	10.8	11.4	1.13	7.33	24.4	146	0.373	2.46	1.67	2.14	4.05	4	11.5	11.6	93.1
10VNBH201	2-Nov-10	Soil	0-15	5.33	8.13	5.72	26.7	126	654	0.573	6.02	6.54	12.9	16.2	14.4	8.43	8.47	62.9
10VNBH202	2-Nov-10	Soil	0-20	425	645	293	346	286	933	26.2	220	202	57	38.3	27.4	460	459	92.6
10VNBH203	2-Nov-10	Soil	0-20	15.4	17.1	4.55	10.9	18	86.2	1.24	3.99	5.44	1.63	1.47	2.71	17.1	17.1	90.1
10VNBH400	2-Nov-10	Sediment	0-10	62.8	77.1	19.2	74.1	294	1430	2.73	20.3	21.7	18.1	18.6	19.4	68.3	68.5	91.7
10VNBH402	2-Nov-10	Sediment	0-50	362	394	27.8	63	118	517	38.1	108	92.4	30.4	18.3	11.8	372	372	97.3
10VNBH403	2-Nov-10	Sediment	0-130	37.4	42.2	2.17	9.95	42.2	216	1.34	10.4	8	5.97	8.95	7.24	38.2	38.2	97.9
10VNBH404	2-Nov-10	Sediment	0-50	4.9	7.63	1.18	3.61	19.9	86.2	0.463	10.5	0.625	1.77	3.08	3.4	5.67	5.66	86.6
10VNBH406	2-Nov-10	Sediment	0-200	257	316	39.8	34.8	49.5	319	38.1	152	73.9	12.5	7.93	9.64	268	268	95.9
<i>Southern Perimeter (Bien Hoa City)</i>																		
10VNBH429	6-Nov-10	Sediment	0-20	24.3	24.3	< 2.22	6.66	31	393	< 2.23	< 2.23	5.27	3.92	< 1.46	14.9	27.1	26.9	90.3
10VNBH430	6-Nov-10	Sediment	0-100	79.1	106	3.23	208	745	5010	29.3	98.3	52.8	40.7	170	213	95.5	95.6	82.7

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

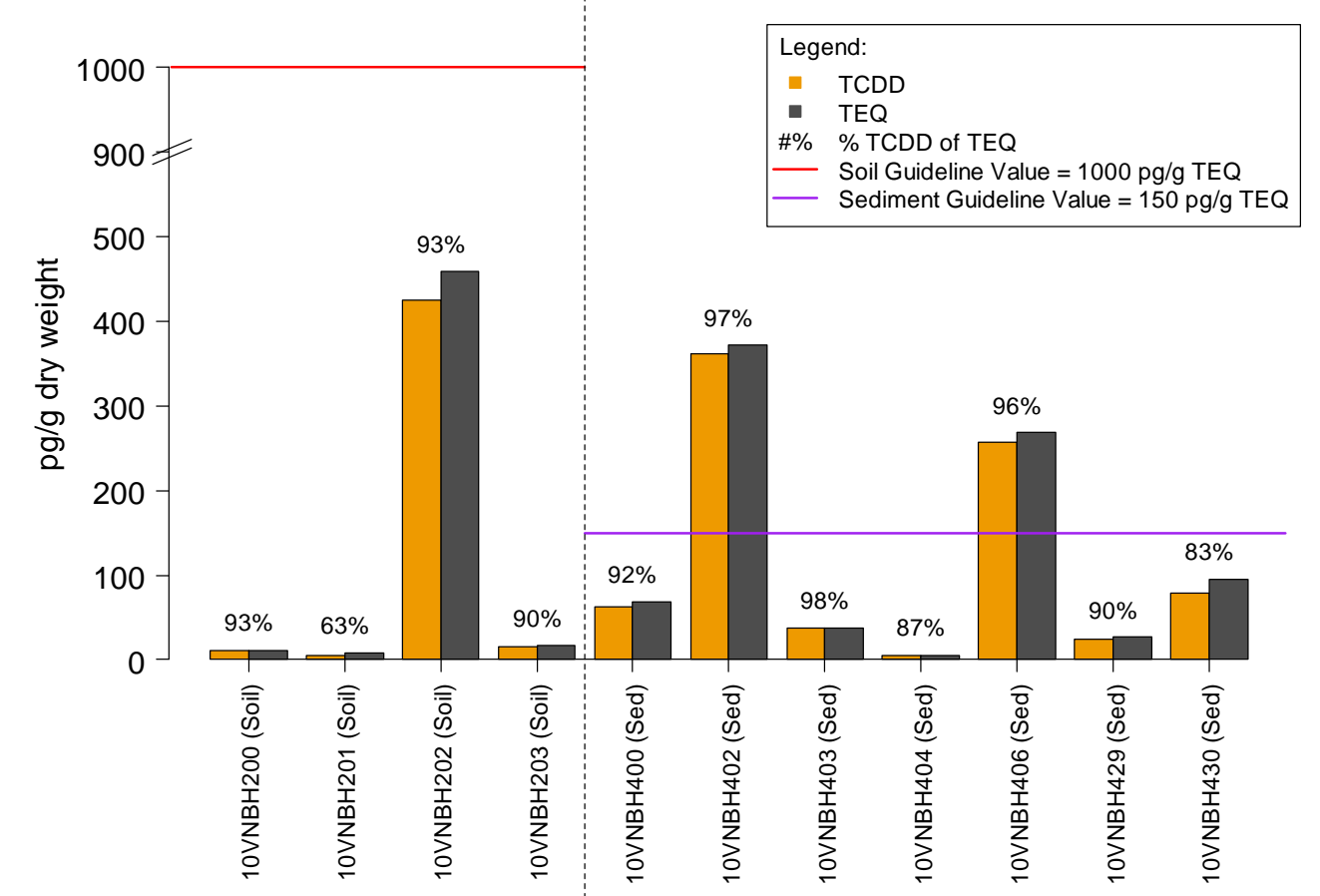
Orange shading indicates value exceeds Vietnamese guideline - 1,000 pg/g TEQ in soil (TCVN 8183:2009).

Red shading indicates value exceeds Vietnamese guideline - 150 pg/g TEQ in sediment (TCVN 8183:2009).

Figure 3.5 Soil and sediment sampling locations on the perimeter of Bien Hoa Airbase and Bien Hoa City, Viet Nam, 2004 to 2010.



TCDD (pg/g dry weight, TEQ (pg/g) and percent TCDD of TEQ in soil and sediment samples collected from the perimeters of Bien Hoa Airbase, Viet Nam, November 2010.



Legend

- ⬢ Airport Boundary
- ⬢ Ward Boundary
- ⬢ Landfill
- ➔ Direction of runoff

Soils/Sediment:

■ 2010 (Hatfield/Office 33)	■ 2010 (Hatfield/Office 33)
▲ 2008 (Hatfield/VRTC)	▲ 2008 (Hatfield/VRTC)
● 2004/2005 (Hatfield/10-80)	● 2004/2005 (Hatfield/10-80)

*Vietnamese National Standard for Dioxin
TCVN 8183:2009 (1000 ppt Soil,
150 ppt Sediment).

0 0.2 0.4 0.8 Km
Scale: 1:25,000
Projection: WGS 1984 UTM Zone 48N

Data Sources:
a) Image acquired from World View 2010
b) Sampling Locations from Hatfield/VRTC and 10-80
c) Ward boundaries estimated from: KAP of Local Residents at a Dioxin Hotspot - Bien Hoa - Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008

3.1.6 Other Soil and Sediment Analyses

One soil sample (10VNBH701) and one sediment sample (10VNBH428) were analysed by the ALS Laboratory Group, Saskatoon, SK, Canada for Total Organic Carbon (TOC) and particle size (Table 3.6).

3.1.6.1 Total Organic Carbon (TOC)

Levels of TOC should be considered when reviewing contaminant levels in soils and sediments, as many contaminants preferentially partition into, or bind onto, organic material. Sample 10VNBH701 (a duplicate of sample 10VNBH210 collected from the northeast perimeter of the Airbase) exhibited a TOC level of 0.8%, consistent with the generally sandy nature of soils on the Airbase. The sediment sample had an intermediate TOC level of 2.71%.

3.1.6.2 Particle Size Analysis (PSA)

PSA analyses were completed for selected soil and sediment samples (10VNBH701 and 10VNBH428, respectively). The percentage of gravel (>2 mm), sand (2 mm – 0.063mm), silt (0.063 mm – 4 µm), and clay (>4 µm) can impact contaminant levels in soils and sediments. In general, soils with high gravel and sand content retain lower levels of contaminants than soils predominantly composed of silt and clay. Sand dominated the PSA profiles of the samples analysed (88.7% in 10VNBH701, and 62.8% in 10VNBH428). As expected, the sediment sample contained higher silt (18.7%) and clay (13.3%) content.

Table 3.6 Particle size and carbon content in selected soil and sediment samples, Bien Hoa, Viet Nam, November 2010.

Sample ID	Location	Matrix	Particle Size				Total Organic Carbon (%)
			% Gravel (>2 mm)	% Sand (2.0 mm to 0.063 mm)	% Silt (0.063mm to 4 µm)	% Clay (<4 µm)	
10VNBH701	NE Perimeter	Soil	1.71	88.7	8.20	1.39	0.80
10VNBH428	Z1 Area	Sediment	5.18	62.8	18.7	13.3	2.71

3.1.7 Comparison with Da Nang and Phu Cat Airbase Results

Review of dioxin concentrations at other known Ranch Hand sites in Viet Nam provides useful information for comparative purposes. Significant quantities of TCDD were detected in soil samples analysed from Da Nang Airport in December 2006 and January 2009 (Hatfield/Office 33 2007, 2009), and from Phu Cat Airbase in 2004 and 2005 (Hatfield/10-80 2006) and January 2008 (Hatfield/VRTC 2009). Comparison of results from the three airbases is presented in Table 3.7.

Table 3.7 Highest recorded concentrations of polychlorinated dibenzo-*p*-dioxins in Da Nang, Phu Cat and Bien Hoa airbases, Viet Nam.

	Da Nang	Phu Cat	Bien Hoa
Highest Recorded Dioxin Concentration in Soil	361,000 ppt TCDD	236,000 ppt TCDD	259,000 ppt TCDD
	365,000 ppt TEQ	238,000 ppt TEQ	262,000 ppt TEQ
	99% TCDD of TEQ	99% TCDD of TEQ	99% TCDD of TEQ
	Former Mixing and Loading Area (Hatfield/Office 33 2007)	Former Storage Area (Hatfield/VRTC 2009)	Z1 Area (Hatfield/VRTC 2009)
Highest Recorded Dioxin Concentration in Sediment	8,390 ppt TCDD	194 ppt TCDD	5,810 ppt TCDD
	8,580 ppt TEQ	201 ppt TEQ	5,970 ppt TEQ
	98% TCDD of TEQ	96% TCDD of TEQ	97% TCDD of TEQ
	Drainage ditch d/s of Storage Area (Hatfield/Office 33 2009)	East of the Runway (Hatfield/10-80 2006)	Pacer Ivy Area (Hatfield/VRTC 2009)

Soil and sediment samples analysed from the Former Mixing and Loading and Former Storage Areas in northern Da Nang Airport exhibited the highest TCDD levels of all sites sampled by Hatfield to date in Viet Nam. The maximum soil TEQ concentration recorded in 2006 was 365,000 ppt from samples collected at the Former Mixing and Loading Area; this is 365 times the Vietnamese and globally acceptable maximum standard of 1,000 ppt. Three soil samples were >100,000 ppt; seventeen (17) of the 23 soil samples (74%) analysed from Da Nang Airport were >1,000 ppt. TCDD levels measured in 2009 in the central and southern Da Nang Airport areas were significantly lower than contaminant levels detected in the north; TCDD concentrations ranged between 0.388 ppt and 145 ppt, with the exception of the Pacer Ivy Storage Area, where one soil sample exhibited 13,400 ppt TCDD and 20,600 ppt TEQ (65% TCDD of TEQ). Dioxin concentrations in sediments of Sen Lake and North Airport drainage ditches exceeded the Vietnamese guideline of 150 ppt TEQ; TEQs from 2006 and 2009 sediment samples from the North Airport sites ranged from 674 to 8,580 ppt.

At Phu Cat Airbase, the highest dioxin concentrations were detected in the Storage Area (236,000 ppt TCDD; 238,000 TEQ; 99.2% TCDD of TEQ) during the Hatfield/VRTC (2009) study. Most samples collected from this area exhibited dioxin levels exceeding 1,000 ppt. TCDD represented over 95% of TEQ in all samples analyzed, verifying the source as being Agent Orange. Dioxin concentrations at Phu Cat Airbase are comparable to those found at Bien Hoa and Da Nang. Highest sediment TCDD level was recorded to the east of the runway (194 ppt), at a location downstream of the suspected Ranch Hand operational area, which was established as a dioxin mitigation site by Vietnamese authorities. Run-off from this site ultimately flows into the South Lake, which is used for irrigation purposes, exposing villagers to dioxins during work in paddies, consumption of fish, and perhaps other food items.

The highest soil dioxin concentrations at Bien Hoa Airbase were recorded during the Hatfield/VRTC (2009) study. A sample collected from a depth of 60-90 cm in Z1 Area (main site for herbicide storage) exhibited a TEQ concentration

of 262,000 ppt (259,000 ppt TCDD; 99% TCDD of TEQ). High concentrations (>26,000 ppt TEQ) were detected at all depths sampled at this site. Previous VRTC studies, however, found several samples >1 million ppt at Bien Hoa prior to construction of the landfill (N.X. Truong, pers. comm). Contaminated soils in the Z1 Area have now been contained in a secure landfill, and dioxin levels in and around this area have been reduced significantly as a result. Highest sediment dioxin levels were recorded in samples collected from the Pacer Ivy Area in 2008 (5,970 ppt TEQ; Hatfield/VRTC 2009) and 2010 (2,020 ppt TEQ).

Overall, Da Nang, Phu Cat and Bien Hoa airbases have exhibited comparable soil dioxin concentrations. As former Ranch Hand operation sites, these three airbases are confirmed as the most significant dioxin hotspots in the country. Highest sediment TEQ concentrations recorded were lower at the Phu Cat Airbase relative to the other airbases; however, they remained above the Vietnamese standard (150 ppt TEQ). As of 2010, dioxin continues to enter the aquatic ecosystem, the general environment and the food chain in and around Da Nang, Phu Cat and Bien Hoa airbases. Dioxin levels recorded in soil and sediment samples at all three airbases continue to exceed all international standards and guidelines for these toxic chemicals. Remediation activities at Bien Hoa in the Z1 Area have helped significantly reduce dioxin levels in the main hotspot area, but it is clear that other hotspots exist on the Airbase, which need to be treated. Lessons learned from ongoing cleanup activities at Da Nang Airport (funded by the US Government) will be invaluable for the future remediation of Bien Hoa and Phu Cat Airbases.

3.1.8 Summary Discussion – Soil and Sediment

Soil and sediment samples analyzed in 2010 at and around Bien Hoa Airbase (i.e., Z1 Area, southwest corner of Airbase, northeastern perimeter, northern perimeter and Bien Hoa City) generally exhibited lower levels of dioxin contamination than those collected from the Pacer Ivy Area. Eight (8) soil samples and six (6) sediment samples from the Pacer Ivy Area exceeded the TEQ guidelines of 1,000 ppt for soil and 150 ppt for sediment. Soil and sediment samples with high TEQ concentrations exceeding these guidelines were also recorded in all other areas sampled.

In the Hatfield/VRTC (2009) study of dioxin concentrations in Bien Hoa Airbase, the highest concentration of TCDD in soil was recorded at site 08VNBH080-3 (depth of 60-90 cm) in the Z1 Area (259,000 ppt TCDD and 262,000 ppt TEQ). Samples taken at a depth profile at this same site all exhibited extremely high TEQ concentrations (>26,400 ppt). The highest TCDD concentration in sediment was recorded during the Hatfield/VRTC (2009) study in a sample collected from the Pacer Ivy Area. Sample 08VNBH111 exhibited a TCDD concentration of 5,810 ppt, TEQ of 5,970 ppt and 97.3% TCDD of TEQ. All 2010 samples analysed from inside and outside the Airbase had TCDD concentrations lower than historical samples from 2009.

Agent Orange continues to contribute to the high concentrations of TCDD in soil and sediment samples in the Pacer Ivy Area of Bien Hoa Airbase (Table 3.1 and Figure 3.1). Soil and sediment samples analyzed to the west of the concrete yard

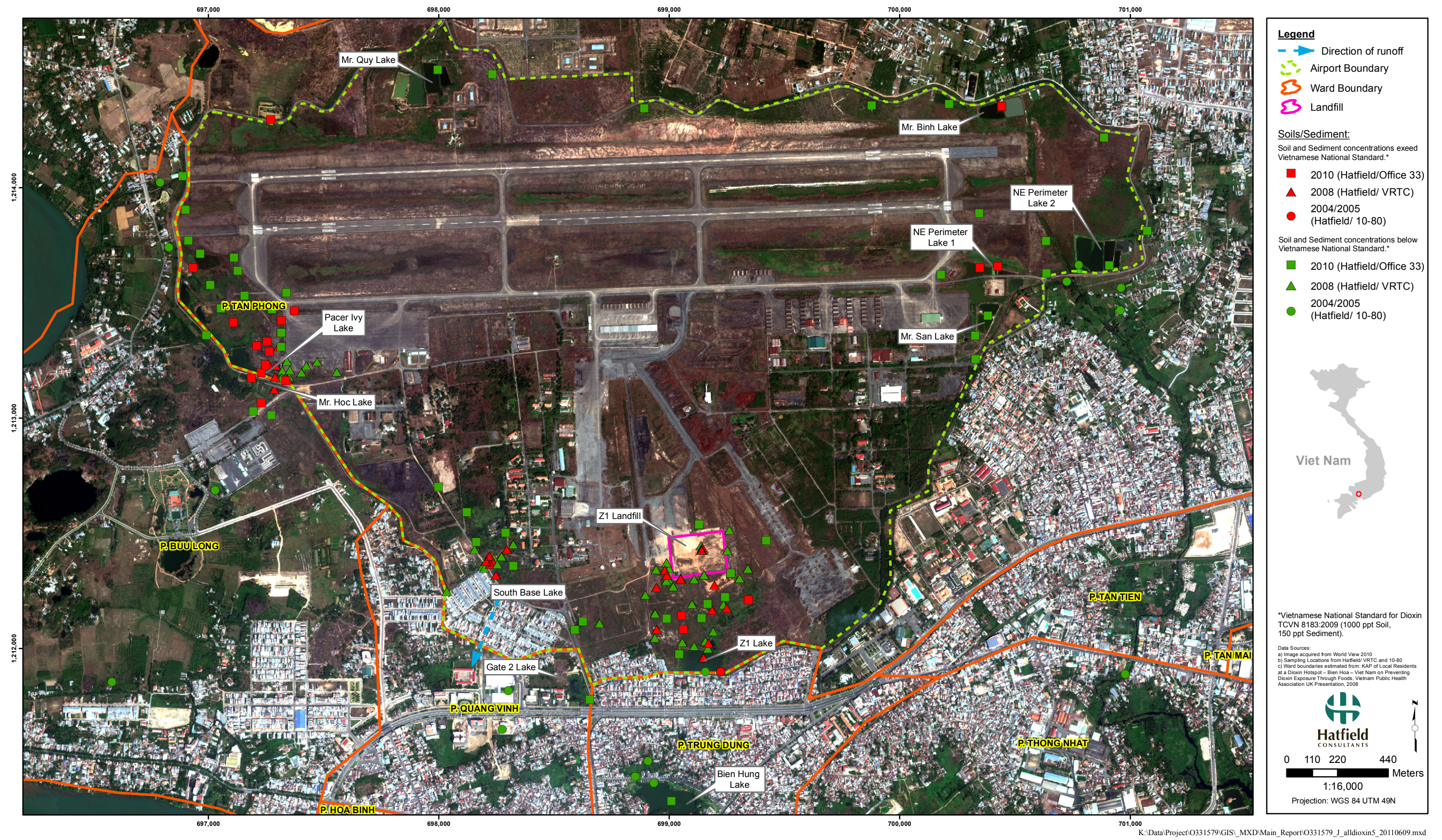
exhibited extremely high TCDD levels in 2010. Site 10VNBH237-2 (at a depth of 30-60cm) exhibited the highest recorded soil TEQ concentrations in Bien Hoa in 2010 (61,800 ppt); a soil sample taken very close to this site (08VNBH105) during the 2008 sampling program (Hatfield/VRTC 2009) also exhibited extremely high levels of contamination (22,300 ppt TCDD, 22,800 ppt TEQ, and 97.8% TCDD of TEQ). Sediment samples taken from the Pacer Ivy Area also exhibited high dioxin levels, exceeding the TEQ guideline of 150 ppt. The highest sediment TEQ concentration recorded in 2010 was in sample 10VNBH424 (2,020 ppt). Dioxin levels at the Pacer Ivy Area exceeds Vietnamese and international guidelines by significant margins. Guideline levels set in Canada, the US EPA and Finland are the most conservative and were exceeded by the greatest margin.

Hatfield/VRTC/Office 33 (2009 and 2010) studies found that soil and sediment samples collected from the area to the south and southwest of the Z1 contaminated area had higher levels of dioxins than samples collected from the area east and north of the landfill. The highest soil TEQ concentration in the Z1 Area during the 2010 study was recorded in sample 10VNBH242 (3,210 ppt) located to the south of the landfill.

Soil and sediment samples exceeding the Vietnamese TEQ guidelines were also observed in the northeastern perimeter of the Airbase. One soil sample taken from this area had a TEQ value of 1,040 ppt; a sediment sample analyzed from 'NE Perimeter Lake 2' also exhibited a high TEQ of 633 ppt (Table 3.4 and Figure 3.4)

A soil sample collected from SW Airbase also exhibited high levels of TCDD (3,640 ppt) and TEQ (5,150 ppt TEQ); the sample was archived from the 2008 program (08VNBH071). TCDD concentrations in all samples collected in 2010 from the SW Airbase were relatively low (ranged between 7.84 ppt and 124 ppt). These concentrations were significantly lower than 2008 concentrations (65,400 ppt TCDD; Hatfield/VRTC 2009). The TEQ concentrations in soil samples collected from the northern perimeter of the Airbase were also low (8.47 to 459 ppt); however, sediment samples exceeding the TEQ guideline (150 ppt) were recorded in several lakes and ponds.

Figure 3.6 Summary of TEQ values (pg/g dry weight) for soil and sediment samples analyzed in Bien Hoa, Viet Nam, 2004 to 2010.



3.2 FISH

Dioxin/furan concentrations in fish tissues were determined from several lakes (N = 11) on Bien Hoa Airbase and Bien Hoa City. At least one of the fish tissue samples analyzed from each of the lakes and ponds in 2010 from the Bien Hoa Airbase and its vicinity were above Health Canada consumption guidelines (20 ppt for edible fish tissue). Fish tissues sampled from market places outside the Airbase (Gate 2 Market and Bien Hoa Market) did not exceed Health Canada consumption guidelines. Results from the 2010 sampling program are provided in Table 3.8, and discussed the following sections.

3.2.1 Z1 Area

In November 2010, Tilapia were collected from Z1 Lake, located south of the main hotspot, on the southern perimeter of the Airbase. Muscle tissue from a composite of 13 small Tilapia from the Z1 Lake had a TEQ concentration of 18.9 ppt (wet weight), which was below the Health Canada consumption guideline. Fat tissue taken from the same Tilapia composite had an extremely high TEQ concentration (1,440 ppt; 97.9% TCDD), indicating Agent Orange as the source of the contamination. Whole fish tissue (full body composite analysis) taken from a composite of 8 small Tilapia from Z1 Lake also had a very high TEQ of 96.5 ppt (TCDD 98.1% of the TEQ).



Source: Hatfield Consultants

Table 3.8 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in fish tissue samples (pg/g [ppt] wet weight), Bien Hoa, Viet Nam, November 2010.

Sample ID	Location	Fish Species (Common Name)	Tissue Type	PCDD (pg/g dry weight)						PCDF (pg/g dry weight)						TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)		
				2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF					
<i>NE Perimeter</i>																				
10VNBH500	Mr. San Lake	Tilapia	Muscle	1.4	1.4	<0.0499	<0.0499	<0.0499	NDR 0.105	0.253	0.4	0.0574	<0.0499	<0.0499	<0.0499	1.5	1.49	94.0		
10VNBH501	Mr. San Lake	Tilapia	Fat	73.3	76.9	<0.494	3.6	9.59	40.1	15.7	24.4	3.49	<0.494	0.854	1.46	76.3	76	96.4		
10VNBH502	NE Perimeter	Tilapia	Muscle	14.4	14.4	<0.0501	<0.0501	<0.0501	0.0945	3.41	3.8	0.0696	<0.0501	<0.0501	<0.0501	14.8	14.8	97.3		
10VNBH503	NE Perimeter	Tilapia	Fat	1620	1630	17.2	3.09	2.63	3.63	487	472	18.3	0.512	<0.460	<0.460	1680	1680	96.4		
<i>Northern Perimeter</i>																				
10VNBH504	Mr. Quy Lake	Tilapia	Muscle	25.4	25.5	0.187	0.053	0.105	0.504	2.53	3.02	<0.0455	<0.0455	<0.0455	<0.0455	25.9	25.9	98.1		
10VNBH505	Mr. Quy Lake	Tilapia	Fat	2410	2410	27.7	10.7	15.4	25.4	306	310	21.5	1.25	<0.497	0.776	2460	2460	98.0		
<i>Pacer Ivy Area</i>																				
10VNBH509	Mr. Hoc Lake	Tilapia	Muscle	31.2	31.2	0.072	<0.0485	<0.0485	0.0886	2.21	2.85	0.0517	<0.0485	<0.0564	<0.0485	31.5	31.5	99.0		
10VNBH510	Mr. Hoc Lake	Tilapia	Fat	3990	4000	14.4	7.74	3.65	8.48	339	334	10.7	<0.461	<0.461	<0.461	4040	4040	98.8		
10VNBH521	Pacer Ivy Lake	Tilapia	Whole Fish	618	618	4.07	6.92	5.14	8.69	2.81	4.54	0.323	0.1	0.285	0.333	622	622	99.4		
<i>Z1 Area</i>																				
10VNBH516	Z1 Lake	Tilapia	Muscle	18.6	18.6	0.123	<0.0487	0.069	0.0852	1.65	1.91	<0.0487	<0.0487	<0.0487	<0.0487	18.9	18.9	98.4		
10VNBH517	Z1 Lake	Tilapia	Fat	1410	1420	16.4	3.93	3.19	10.4	158	183	17	1.03	<0.494	<0.494	1440	1440	97.9		
10VNBH522	Z1 Lake	Tilapia	Whole Fish	94.7	95.8	2.08	3.52	11.6	57.9	7.64	11.7	4.06	1.5	1.82	1.96	96.5	96.5	98.1		
<i>Outside Airbase</i>																				
10VNBH507	Gate 2 Lake	Tilapia	Muscle	32.7	32.7	0.233	0.081	0.08	0.226	2.76	3.75	0.129	<0.0496	<0.0496	<0.0496	33.2	33.2	98.5		
10VNBH508	Gate 2 Lake	Tilapia	Fat	1490	1490	13.8	5.82	3.56	3.73	162	189	5.69	0.807	<0.393	<0.393	1520	1520	98.0		
10VNBH512	Gate 2 Market	Tilapia	Muscle	NDR	<0.0499	<0.0499	<0.0499	0.059	0.123	NDR	0.066	<0.0499	<0.0499	<0.0499	<0.0499	0.0837	0.0782	NC		
10VNBH513	Gate 2 Market	Tilapia	Fat	0.0862	2.51	4.66	1.17	1.56	1.93	2.69	0.0530	2.01	6.95	1.78	<0.492	<0.492	<0.492	4.78	4.54	55.3
10VNBH514	Bien Hoa Market	Tilapia	Muscle	NDR	<0.0500	<0.0500	0.05	<0.0500	0.0899	0.065	0.114	<0.0500	<0.0500	<0.0525	<0.0500	0.0911	0.0856	NC		
10VNBH515	Bien Hoa Market	Tilapia	Fat	0.117	3.29	5.49	1.55	1.57	1.5	3.55	2.85	5.75	4.64	<0.481	<0.481	<0.481	6.21	5.9	55.8	
10VNBH518	Bien Hung Lake	Tilapia	Muscle	1.25	1.25	<0.0500	<0.0500	<0.0500	0.0622	0.526	0.603	<0.0500	<0.0500	<0.0596	<0.0500	1.36	1.35	92.6		
10VNBH519	Bien Hung Lake	Tilapia	Fat	86.7	86.7	<0.468	<0.468	2.32	39.2	44.8	53.6	1.44	<0.468	1.07	1.13	91.9	91.8	94.4		

NC= Not calculated (e.g., samples with 2,3,7,8-TCDD concentrations that were NDR - not quantifiable).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Non-detect ratio; peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND ("0").

Large comp. = A composite sample of the 6 largest Tilapia collected.

Small comp. = A composite sample of the 6 smallest Tilapia collected.

■ Red shading indicates value exceeds Health Canada consumption guideline 2009 - 20 pg/g TEQ in edible fish.

3.2.2 Pacer Ivy Area

In 2010, fish muscle, fat and whole fish tissues were sampled from 'Mr. Hoc Lake' and 'Pacer Ivy Lake' in the Pacer Ivy Area. All fish tissue samples analysed from this area exceeded Health Canada consumption guideline of 20 ppt. In 'Mr. Hoc Lake', a composite of Tilapia (n=3) were analyzed for dioxins in muscle and fat tissues. The muscle sample had a TEQ concentration of 31.5 ppt (99% TCDD), while the fat tissue sample exhibited an extremely high TEQ of 4,040 ppt (98.8% TCDD). A composite of 15 Tilapia sampled from the small pond north of 'Mr. Hoc Lake' also had a high TEQ (622 ppt), with TCDD making up 99.4% of the TEQ. Given that all samples exhibited a TCDD to TEQ proportion of 98% or greater indicates that Agent Orange is the source of contamination.

3.2.3 Northeastern Perimeter

Fish muscle and fat tissues were sampled from 'Mr. San Lake' and the 'NE Perimeter Lake 1' in the northeastern Airbase in 2010. A composite of 6 Tilapia were sampled from each lake. The muscle tissue sample analysed from 'Mr. San Lake' had a low TEQ concentration (1.49 ppt). The fat tissue had a higher TEQ (76 ppt), and a proportion of TCDD to the TEQ concentration of 96.4%, indicating Agent Orange as the source of contamination. In 'NE Perimeter Lake 1', the TEQ concentration in the fat tissue was extremely high (1,680 ppt). TCDD comprised 96.4% of the TEQ concentration in the fat tissue, again indicating that Agent Orange is the source of contamination.

3.2.4 Northern Perimeter

In 2010, fish samples were collected from 'Mr. Quy Lake' near the northern perimeter of the Bien Hoa Airbase. Muscle and fat tissues sampled from a composite of 3 Tilapia from this lake exceeded Health Canada consumption guidelines of 20 ppt for dioxins. Muscle tissue of the Tilapia composite exhibited a TEQ concentration of 25.9 ppt, while the fat tissue was extremely high (2,460 ppt TEQ). The proportion of TCDD in the TEQ of muscle and fat tissues were 98.1% and 98%, respectively, clearly indicating Agent Orange as the source of contamination in this lake.

3.2.5 Bien Hoa City (Lakes and Markets)

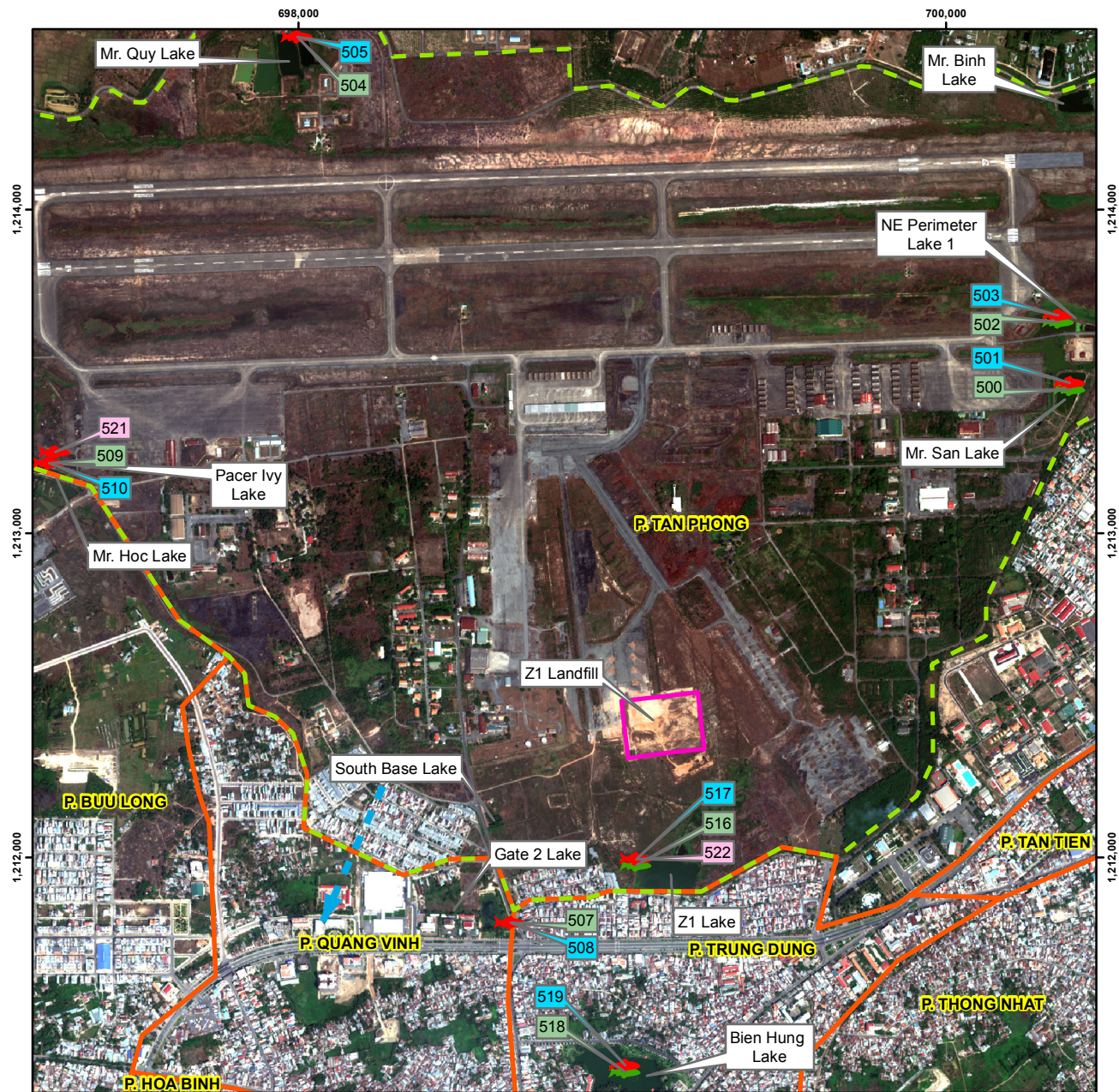
Tilapia were sampled from 'Gate 2 Lake', Bien Hung Lake, Gate 2 Market, and Bien Hoa Market, located outside the Airbase in Bien Hoa City. Muscle and fat tissue samples collected from a composite of 5 Tilapia from 'Gate 2 Lake' (outside the southern perimeter of the Airbase) exhibited TEQ concentrations well above Health Canada consumption guideline of 20 ppt. Muscle tissue had a TEQ concentration of 33.2 ppt (98.5% TCDD), and the fat tissue had a TEQ of 1,520 ppt (98% TCDD). In Bien Hung Lake, the Tilapia composite (n=2) sample exhibited a low TEQ concentration in muscle tissue (1.35 ppt), but a high concentration in fat tissue (91.8 ppt). TCDD comprised 92.6% of the TEQ in muscle tissue and 94.4% in the fat tissue, indicating Agent Orange as the contaminant source.

Fish sampled in Gate 2 Market and Bien Hoa Market exhibited low TEQ concentrations. Muscle tissues sampled from both markets had very low TEQ concentrations (NDR 0.0782 ppt from Gate 2 Market and NDR 0.0856 ppt from Bien Hoa Market). Fat tissues sampled had slightly higher TEQ concentrations: 4.54 ppt (55.3% TCDD) from Gate 2 Market and 5.9 ppt (55.8% TCDD) in Bien Hoa Market. These concentrations are lower than Health Canada guidelines. It is likely that these fish, sampled from the markets, originated from aquaculture ponds in the Don't Nai River (according to interviews with the market sellers). However, considering that Tilapia sampled inside the Bien Hoa Airbase exhibited extremely high TEQ concentrations, and fish caught inside the Airbase are sold in outside markets, the cultivation and sale of fish from the Airbase should be prohibited immediately.



Source: Hatfield Consultants

Figure 3.7 Fish sampling locations, Bien Hoa Airbase and Bien Hoa City, Viet Nam, November 2010.



Legend

- Direction of runoff
- Airport Boundary
- Ward Boundary
- Landfill
- 502 Fat Tissue Samples
- 503 Muscle Tissue Samples
- 504 Whole Fish Samples

Fish:

- Concentrations exceed Health Canada Guideline**
- Concentrations below Health Canada Guideline**
- 2010 (Hatfield/Office 33)

Scale: 0 0.15 0.3 0.6 Km
Scale: 1:20,000
Projection: WGS 1984 UTM Zone 48N

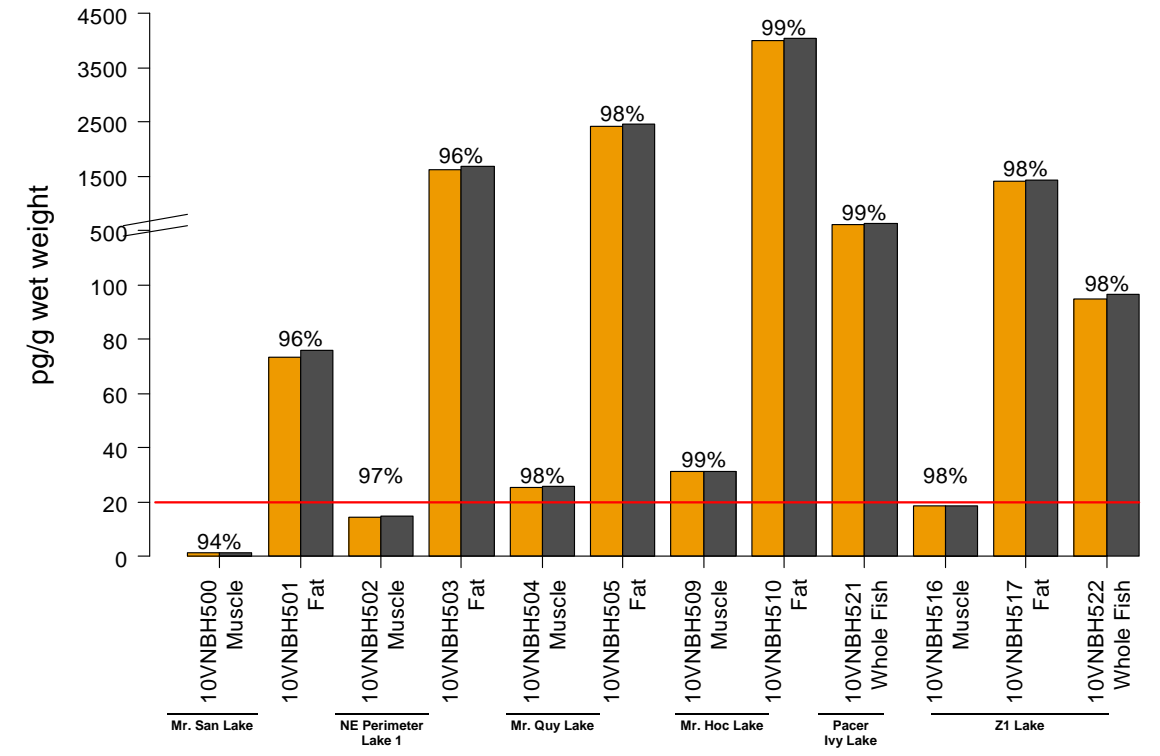
Hatfield CONSULTANTS

Viet Nam

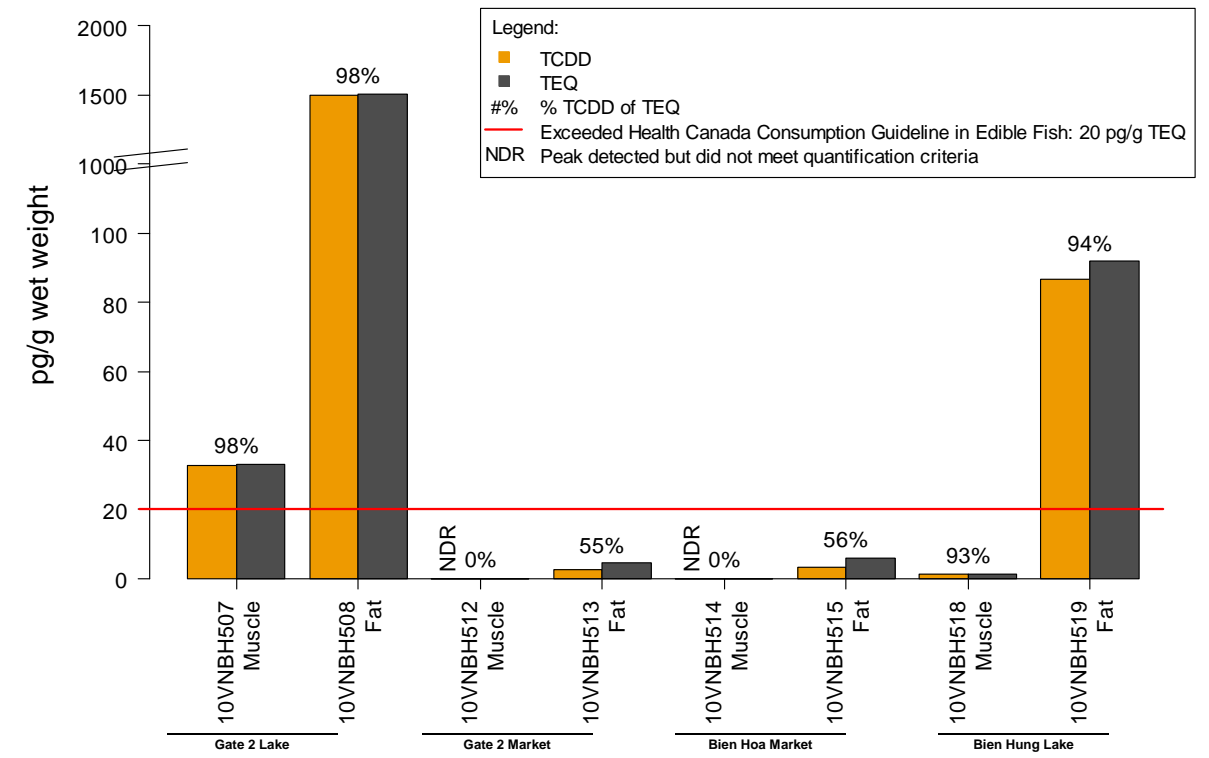
Data Sources:
a) Image acquired from World View 2010
b) Sampling Locations from Hatfield/VRTC and 10-80
c) Ward boundaries estimated from: KAP of Local Residents at a Dioxin Hotspot - Bien Hoa - Viet Nam on Preventing Dioxin Exposure Through Foods, Vietnam Public Health Association UK Presentation, 2008

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TCDD (pg/g wet weight, TEQ (pg/g) and percent TCDD of TEQ in talapia fish samples collected inside the Bien Hoa Airbase, Viet Nam, November 2010.



TCDD (pg/g wet weight, TEQ (pg/g) and percent TCDD of TEQ in talapia fish samples collected from Bien Hoa City, Viet Nam, November 2010.



3.2.6 Comparison with Da Nang Results (2006 and 2009)

Studies conducted by Hatfield/Office 33 in Da Nang in 2006 and 2009 (Hatfield/Office 33 2007, 2009) found that Sen Lake A, located in the northern part of the Da Nang Airport, downstream of the main dioxin hotspot areas, exhibited the highest recorded total TEQ in fish fat in Viet Nam to date. In 2009, Tilapia fat taken from a composite of 6 large Tilapia (average weight 439.8 g) exhibited contaminant concentrations as high as 8,350 ppt TEQ and 7,920 ppt TCDD. Muscle (88.2 ppt TEQ), egg (1,290 ppt TEQ), and liver (1,540 ppt TEQ) tissues analysed from the composite of large Tilapia in Sen Lake all exceeded Health Canada guidelines. In 2006, Tilapia fat tissues analysed from the north Airport also exhibited very high TEQ values (3,120 ppt). Fish sampled from the rest of the lakes and ponds inside the airport generally remained below the Health Canada guideline.

In Bien Hoa, Tilapia sampled from all lakes and ponds inside and outside the Airbase exhibited very high contaminant concentrations in fat tissue, well exceeding the designated Health Canada guideline. In 2010, the highest recorded fish TEQ level in Bien Hoa was found in fat tissue of a Tilapia composite (n=3) in 'Mr. Hoc Lake', Pacer Ivy Area (4,040 ppt TEQ; 3,990 ppt TCDD). Muscle samples from 'Mr. Quy Lake' (25.9 ppt TEQ), 'Mr. Hoc Lake' (31.5 ppt TEQ) and 'Gate 2 Lake' (33.2 ppt TEQ) exhibited TEQ values exceeding Health Canada consumption guidelines. In the 2010 samples collected from lakes inside and outside the Airbase (market places excluded), over 90% of the TEQ was attributed to TCDD. Only the fish sampled from Gate 2 Market and Bien Hoa Market exhibited contaminant concentrations below the Health Canada guideline.

Fish sampling results from Da Nang Airport (Hatfield/Office 33 2007, 2009) and the 2010 Bien Hoa Study are comparable. Dioxin concentrations in Tilapia fat tissue sampled from Sen Lake A (8,350 ppt TEQ and 7,920 ppt TCDD) in Da Nang Airport remains the highest recorded in Viet Nam to date; Tilapia fat tissue sampled from 'Mr. Hoc Lake' in Bien Hoa Airbase (2010) recorded the second highest TEQ value (4,040 ppt). Dioxin contamination in fish from the Da Nang Airport appears to be concentrated in the northern part of the airport, in Sen Lake A and other surrounding lakes located near former hotspot areas. In Bien Hoa, very high dioxin levels are detected in fish sampled from lakes and ponds throughout the Airbase and its vicinity, indicating more widespread contamination.

3.2.7 Summary of Fish Data

The Pacer Ivy Area had the highest level of dioxin contamination in bottom sediments of all water bodies sampled, both inside and outside of Bien Hoa Airbase. Consequently, fish captured in 'Mr. Hoc Lake' from this area contained the highest level of TCDD recorded in biological tissues (4,040 ppt in fat; Table 3.8). This value exceeds the Health Canada guideline by >200 times. Extremely high levels of dioxins were also recorded in fish fat from lakes in the northern perimeter, northeastern perimeter, Z1 Area, and Bien Hoa City. Fish

muscle from three of the six lakes sampled ('Mr. Quy Lake', 'Mr. Hoc Lake' and 'Gate 2 Lake') exhibited TEQ values exceeding the Health Canada guideline. Fish sampled from marketplaces outside the Airbase in Bien Hoa City had comparatively low TEQ concentrations in 2010 (NDR 0.0856 ppt for muscle and 5.9 ppt for fat).

In the northern perimeter of the Airbase, fish samples taken from 'Mr. Quy Lake' indicate high contaminant exposure. The TEQ in fish fat was 2,460 ppt, which is >120 times greater than the Health Canada guideline, while the TEQ in muscle (25.9 ppt) also exceeds this guideline. In the Z1 Area (Z1 Lake), the TEQ values in sampled fish fat tissue were 72 times greater than the guideline, while the whole fish tissue exceeded the guideline by 4.8 fold. Fat tissue sampled from the northeastern perimeter of the Airbase also exhibited high TEQ concentrations: 76 ppt in 'Mr. San Lake' (3.8 times greater than guideline) and 1,680 ppt in 'NE Perimeter Lake 1' (84 times greater than guideline).

Given that the Bien Hoa Airbase has a general south sloping topography, dioxins are likely carried through runoff to lakes and ponds located in the south and southeast of the Airbase. As expected, fish sampled from 'Gate 2 Lake' exhibited high TEQ concentrations in both fat and muscle tissues. Fish from Bien Hung Lake also exhibited a high TEQ in fat tissue.

Dai *et al.* (1994b) and Cau *et al.* (1994) reported that by 1998, dioxins had decreased significantly in southern Viet Nam and levels in foodstuffs were considered comparable to those for other nations. However, both authors offered the generalization that residual dioxin contamination in specific locations nonetheless remained a threat to human health in Viet Nam. Hatfield and 10-80 (2000) also confirmed high TCDD levels in fish fat from Aluoi District, in former bomb craters used as aquaculture ponds.

An estimated 25 tons of fish are harvested from lakes and ponds inside the Bien Hoa Airbase every year (Appendix A3.3). Our data confirm extremely elevated levels of TCDD for fish from all lakes and ponds sampled inside the Bien Hoa Airbase and in Bien Hoa City. Health Canada has specific guidelines for consumable tissues. If, for example, fat tissue exceeds 20 ppt TEQ, an assessment of consumption and probable restrictions on intake would be determined for the species of fish involved. Given the fish data presented above, it is suggested that all of the lakes and ponds sampled on Bien Hoa Airbase and immediate vicinities be assigned total fishing/consumption bans.

3.3 HUMAN BLOOD SERUM

3.3.1 Results and Discussion

In 2010, dioxins and furans were analyzed in blood serum from a total of 42 residents of Bien Hoa. Blood donors were sampled from Tan Phong Ward inside the Airbase and Trung Dung Ward to the south of the Airbase in Bien Hoa City. All of the sampled residents (or families of residents) were involved in various occupations inside the Airbase, including working for MND, airport workers, fishermen and farmers. Blood data were collected from 37 male workers

and 5 female workers. Table 3.9 and Figure 3.8 summarize dioxin/furan concentrations in human serum samples collected from workers inside the Bien Hoa Airbase. All serum data are presented on a lipid basis.

Human serum data were collected and analysed for the first time in Bien Hoa under the current study. Schecter *et al.* (2001) collected and analysed 20 whole-blood samples from individuals residing in Bien Hoa City, near the potentially contaminated Bien Hung Lake. Whole-blood samples were also analysed in and around the Da Nang Airport by Hatfield/Office 33 (2007, 2009).

Dioxin and furan data in serum samples were analysed against the WHO's Acceptable Exposure Guidelines calculated based on 1998 Tolerable Daily Intake (see Section 1.4.4). A guideline value of 30 ppt in human serum lipid corresponds to a chronic intake of 4 pg/kg/day. This guideline is used to determine TEQ concentration exceedances.

Among the 42 serum samples analysed from Bien Hoa residents in 2010, three (3) samples recorded extremely high TCDD concentrations. The highest contamination was recorded in serum sample 10VNBH633 (1,970 ppt TCDD; 2,020 ppt TEQ) belonging to an Airbase worker (male) involved in aquaculture and fishing near the Pacer Ivy Area, Bien Hung Lake, South Base Lake and Z1 Lake, and wetlands. His spouse (10VNBH637) recorded the second highest TCDD concentration of 1,130 ppt (1,150 ppt TEQ). A serum sample from another Airbase worker (10VNBH604) also exhibited a high dioxin concentration (1,040 ppt TCDD and 1,080 ppt TEQ). TEQ concentrations in these three samples are more than 35 times the WHO 1998 standard (30 ppt). TCDD comprised over 96% of the TEQ in all three serum samples, indicating Agent Orange as the source of contamination.

An additional 38 serum samples (34 males and 4 females), excluding those discussed above, exhibited serum TEQ concentrations exceeding the WHO 1998 acceptable standard; their TEQ concentrations ranged from 31.2 to 347 ppt. Only one sample (10VNBH610) recorded a TEQ value below the WHO 1998 guideline (19.3 ppt).

The percent TCDD of the TEQ ranged from 56.4% to 98.3%. Workers with lower concentrations of TCDD generally exhibited a lower percent TCDD of TEQ. Other dioxin congeners were present in all serum samples analysed in 2010. However, percent TCDD of TEQ remained relatively high for all Airbase workers (TCDD \geq 56% of TEQ), indicating that Agent Orange exposure remains the likely primary source of contamination for these individuals.

Table 3.9 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in human blood serum (pg/g [ppt], lipid basis) from workers at Bien Hoa Airbase, November 2010.

Sample ID	Sex	Age	PCDD (pg/g lipid basis)					PCDF (pg/g lipid basis)					% Lipid	TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)		
			2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF					Total H7CDF	Total O8CDF
10VNBH600	M	45	27.8	27.8	5.87	28.4	62.1	402	< 0.709	< 0.709	6.78	19	16.7	NDR 0.732	0.86	42.7	41.5	67.0
10VNBH601	F	46	58	58	10.7	32	25.6	282	1.52	1.52	8.15	18.9	10.5	< 0.720	0.86	78	76.6	75.7
10VNBH602	M	48	42.1	42.1	8.33	28.8	17.2	225	0.978	0.978	9.29	22.3	11.3	< 0.595	0.94	60.7	58.8	71.6
10VNBH603	M	47	137	137	< 0.701	27.6	29.3	319	NDR 1.40	< 0.701	7.49	17.5	12.1	NDR 0.724	0.87	146	145	94.5
10VNBH604	M	42	1040	1040	25.1	46.7	39.4	275	1.57	1.57	14.1	17.4	23.6	NDR 0.902	0.81	1080	1080	96.3
10VNBH605	M	47	37.7	37.7	5.05	18.5	25.7	346	NDR 1.21	< 0.564	5.88	20	15	< 0.564	1.1	50.1	49	76.9
10VNBH606	M	50	92.8	92.8	9.81	33.3	29.4	249	NDR 1.32	< 0.752	9.93	22.1	17.7	NDR 1.80	0.89	113	111	83.6
10VNBH607	M	47	40.9	40.9	6.21	17.9	11.6	105	1.34	1.34	< 0.564	13.1	6.3	< 0.564	1.1	50.7	50.7	80.7
10VNBH608	M	48	29.9	29.9	4.22	7.27	18.6	109	NDR 0.867	< 0.667	4.71	11.8	7.12	< 0.667	0.9	38.8	37.9	78.9
10VNBH609	M	48	17.6	17.6	7.45	20.7	< 1.12	280	1.55	1.55	6.56	16.3	9.82	< 1.12	0.78	32.5	31.2	56.4
10VNBH610	M	46	13.7	13.7	< 1.09	12.9	25	212	NDR 1.60	< 1.09	5.56	14	11.4	< 1.09	0.63	20.3	19.3	71.0
10VNBH611	M	45	56.5	56.5	6.53	25.5	33.4	214	NDR 1.27	< 0.670	7.24	18.9	13	< 0.670	0.82	71.7	70.2	80.5
10VNBH612	M	47	79	79	11.8	50.8	72.6	596	1.8	1.8	12.8	30.6	22.2	< 0.688	0.9	106	104	76.0
10VNBH613	M	48	53.3	53.3	9.52	47.2	21.6	370	0.526	0.526	9.99	22.3	12.5	NDR 0.666	1.5	75	73.2	72.8
10VNBH614	M	43	327	327	9.04	29.5	72.1	596	3.05	3.05	10.3	35.4	23.4	1.22	0.9	349	347	94.2
10VNBH615	M	46	42.8	42.8	9.82	36.9	42.5	377	2.36	3.11	12.2	28.8	17.1	< 0.610	1	66.2	63.9	67.0
10VNBH616	M	48	45.9	45.9	8.55	33.6	66.2	558	NDR 1.12	< 0.754	< 0.754	23.3	12.9	< 0.754	1.1	61.3	61.3	74.9
10VNBH617	M	47	322	322	12.1	43.2	61.4	547	NDR 1.24	< 0.903	9.81	8.58	29.6	< 0.903	0.71	345	343	93.9
10VNBH618	M	45	67.8	67.8	8.37	25.2	42.4	331	1.53	1.53	8.62	10.5	15.6	< 0.654	0.98	84.9	83.3	81.4
10VNBH619	M	46	38.9	38.9	5.19	18.8	17.5	223	NDR 1.01	< 0.711	5.75	14.6	13.1	< 0.711	0.8	50.8	49.7	78.3
10VNBH620	M	48	32.4	32.4	7.26	22.7	20.4	202	< 0.913	1.1	6	14.1	11.3	< 0.913	0.7	46.8	45.7	70.9
10VNBH621	M	45	95.8	95.8	7.66	22.2	28.6	237	1.01	1.59	6.61	14.4	7.68	0.791	1.2	111	110	87.1
10VNBH622	M	48	274	274	14.9	57.9	77.8	663	NDR 2.64	< 1.04	14	35.5	35	NDR 1.73	0.71	306	303	90.4
10VNBH623	M	47	67.7	67.7	7.6	23.9	14.1	211	1.4	1.4	8.15	18.8	1.01	< 0.719	0.89	84	82.4	82.2
10VNBH624	M	45	72.1	72.1	8.8	36	45	314	NDR 1.47	1.25	< 1.09	22.8	23	< 1.09	0.64	87.9	87.8	82.1
10VNBH625	M	46	44.1	44.1	6.62	22.3	27.4	208	2.29	2.29	7.35	18	< 0.500	0.55	1.2	59	57.5	76.7
10VNBH626	F	46	31.9	31.9	< 0.989	17.5	15.2	261	1.91	3.26	< 0.989	7.5	10.1	< 0.989	0.76	35.8	35.8	89.1
10VNBH627	M	48	71	71	8	31.5	28.8	330	1.98	1.98	10.5	28	19	< 1.44	0.52	91.1	89	79.8
10VNBH628	M	53	159	159	9.43	33.2	33.9	295	4.09	4.09	< 1.02	< 1.02	< 1.04	< 1.02	0.73	173	173	91.9
10VNBH629	F	61	160	160	11.8	31.6	34	260	4.66	4.66	7.02	8.96	8.21	< 0.781	1.1	180	179	89.4
10VNBH630	M	45	85.4	85.4	< 1.49	24.7	28.2	240	NDR 1.99	< 0.864	< 0.864	14.8	14.1	< 1.13	0.8	90.9	90.8	94.1
10VNBH631	M	50	49.5	49.5	4.57	16.9	15.8	182	1.07	1.07	7.26	17.2	8.8	< 0.692	1.1	61.1	59.9	82.6
10VNBH632	M	48	211	211	10.7	30	35.4	311	1.75	1.75	9.07	19.2	10.1	< 0.527	1.5	232	230	91.7
10VNBH633	M	49	1970	1970	34.2	61.4	21.6	163	1.51	1.51	11.4	14.2	8.57	NDR 0.763	0.89	2020	2020	97.5
10VNBH634	M	45	87	87	< 0.970	13.5	24.1	158	1.8	1.8	6.52	16.1	11.8	< 0.970	0.64	94.4	93.1	93.4
10VNBH635	M	47	67.1	67.1	4.75	12.4	12.8	131	2.38	2.38	< 0.536	9.83	5.09	< 0.536	1.7	74.7	74.7	89.8
10VNBH636	M	48	161	161	13.4	44	54.3	449	2.76	2.76	< 0.969	28.3	14.5	< 0.969	0.67	183	183	88.0
10VNBH637	F	38	1130	1130	17.6	44.3	32.8	332	3.24	4.88	< 1.20	10.7	17.6	NDR 1.41	0.51	1150	1150	98.3
10VNBH638	M	48	28.1	28.1	6.79	26.3	36.2	392	NDR 1.03	< 0.989	9.11	29.9	18.5	1.03	0.8	45.8	44.1	63.7
10VNBH639	F	47	102	102	9.54	38.2	60.8	802	1.13	1.13	6.99	19	17.3	1.31	0.77	122	121	84.3
10VNBH640	M	48	34.4	34.4	5.98	22.8	33.3	339	1.78	1.78	6.43	12.3	20.6	< 0.892	0.73	48	46.7	73.7
10VNBH641	M	48	119	119	8.52	38.1	44.3	486	1.13	1.13	8.5	31	22.9	NDR 0.978	0.85	140	138	86.2

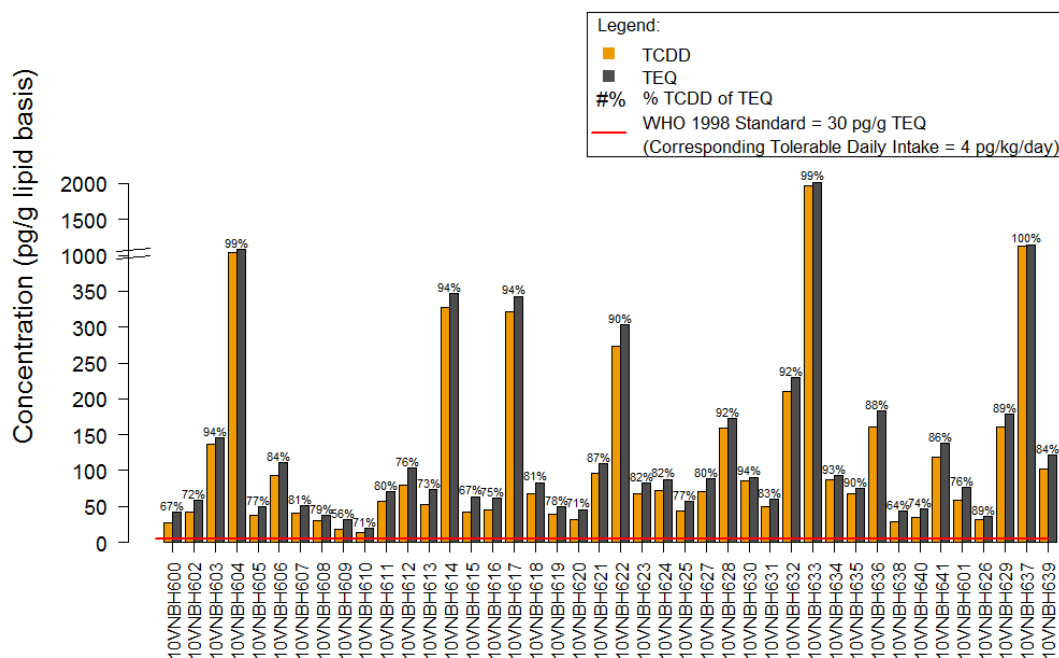
ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND.

Lipid calculations based on "independent" or "factored" analysis (see Appendix A1).

■ Red shading indicates value exceeds the World Health Organization Acceptable Exposure Guidelines (1998) for TCDD in Serum Lipid - 30 ppt corresponding to a chronic intake of 4 pg/kg/day (upper limit).

Figure 3.8 TCDD and total TEQ (pg/g [ppt], lipid basis) for human blood serum, Bien Hoa, Viet Nam, November 2010.



3.3.2 Statistical Analyses of Blood Data

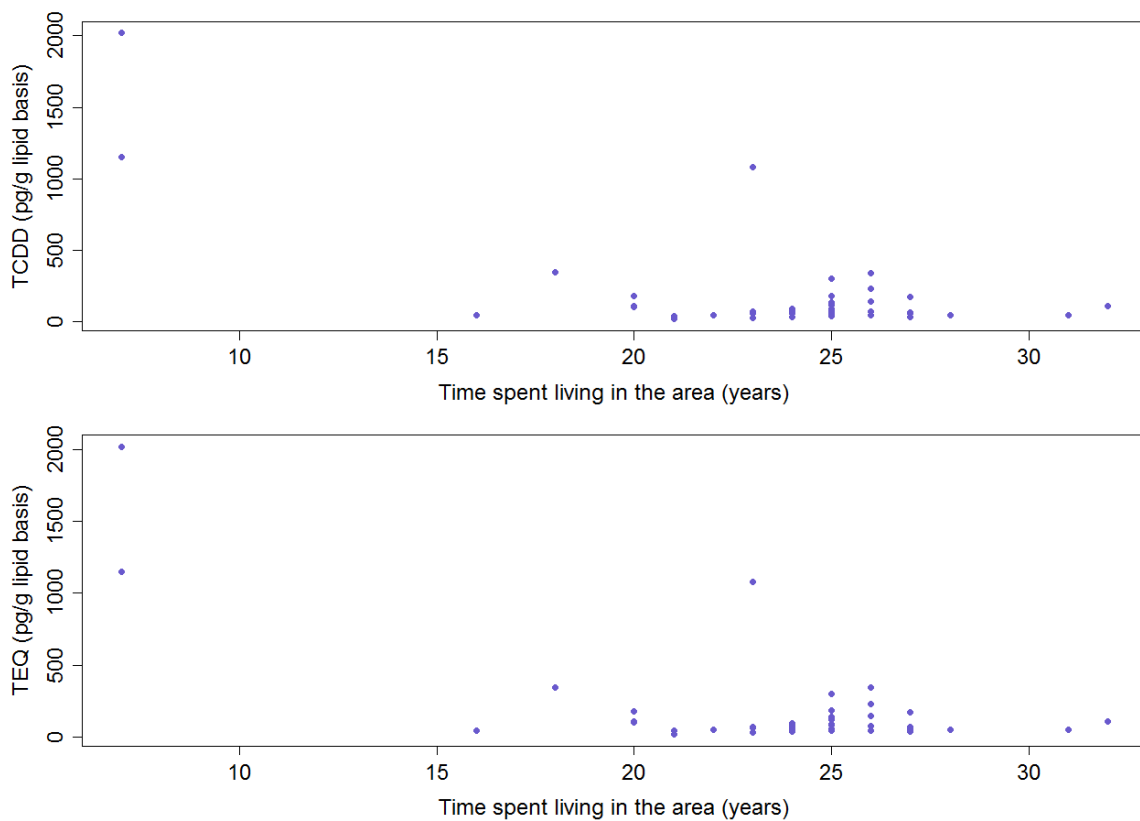
3.3.2.1 Sex-related effects

Differences in the blood dioxin levels of males and females were tested using a Mann-Whitney U test. The results indicated no statistically significant difference in either serum TCDD or serum TEQ between males and females ($p_{TCDD} = 0.4043$; $p_{TEQ} = 0.4489$; data not shown).

3.3.2.2 Effect of the Length of Stay in Bien Hoa Airbase and its Vicinity

The length of time an individual lived inside the Airbase or its vicinity may determine the length of exposure to dioxins. A Spearman's correlation test was carried out to identify a possible relationship between the length of stay in the Bien Hoa area and TCDD and TEQ concentrations in blood serum. A statistically significant correlation was not observed among the two variables ($p_{TCDD} = 0.6406$; $p_{TEQ} = 0.5631$). These results indicate that the length of residence at Bien Hoa Airbase and its vicinity does not affect the dioxin levels in blood serum (Figure 3.9).

Figure 3.9 Relationship between the length of stay at the Bien Hoa Airbase and its vicinity and blood serum TCDD and TEQ (pg/g [ppt], lipid basis) of individuals in Bien Hoa, November 2010.



Source: Hatfield Consultants

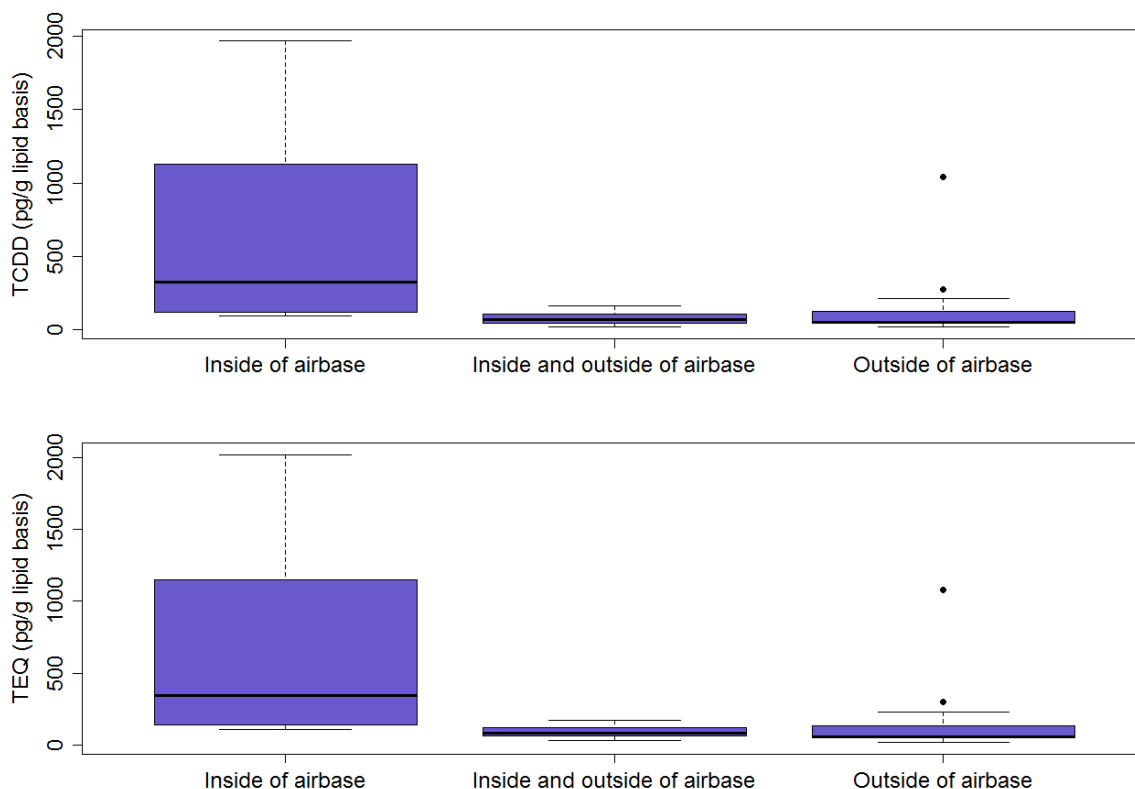
3.3.2.3 Effect of the Length of Employment on the Airbase

A potential relationship between the serum dioxin concentrations of individuals and the number of years they have worked on the Airbase were analysed through Spearman's correlation test. No significant correlation was found between the number of years working in the Airbase and the blood serum TCDD or TEQ values ($p_{TCDD} = 0.4209$; $p_{TEQ} = 0.4386$).

3.3.2.4 Effects of Fishing Location

The present study found high levels of dioxin contamination in Tilapia fat tissues sampled from lakes inside and immediately to the south of the Airbase (see Section 3.2). A Kruskal Wallis Test was carried out to identify a difference in TCDD and TEQ concentrations in individuals fishing in various locations inside and outside the Airbase. A statistically significant difference was found in both TCDD and TEQ concentrations in individuals fishing in lakes inside the Airbase, both inside and outside the Airbase, and only outside the Airbase ($p_{TCDD} = 0.0098$; $p_{TEQ} = 0.0093$). Figure 3.10 shows that individuals fishing exclusively inside the Airbase exhibit higher average TCDD and TEQ concentrations, compared to those who fish both inside and outside the Airbase, and only outside the Airbase.

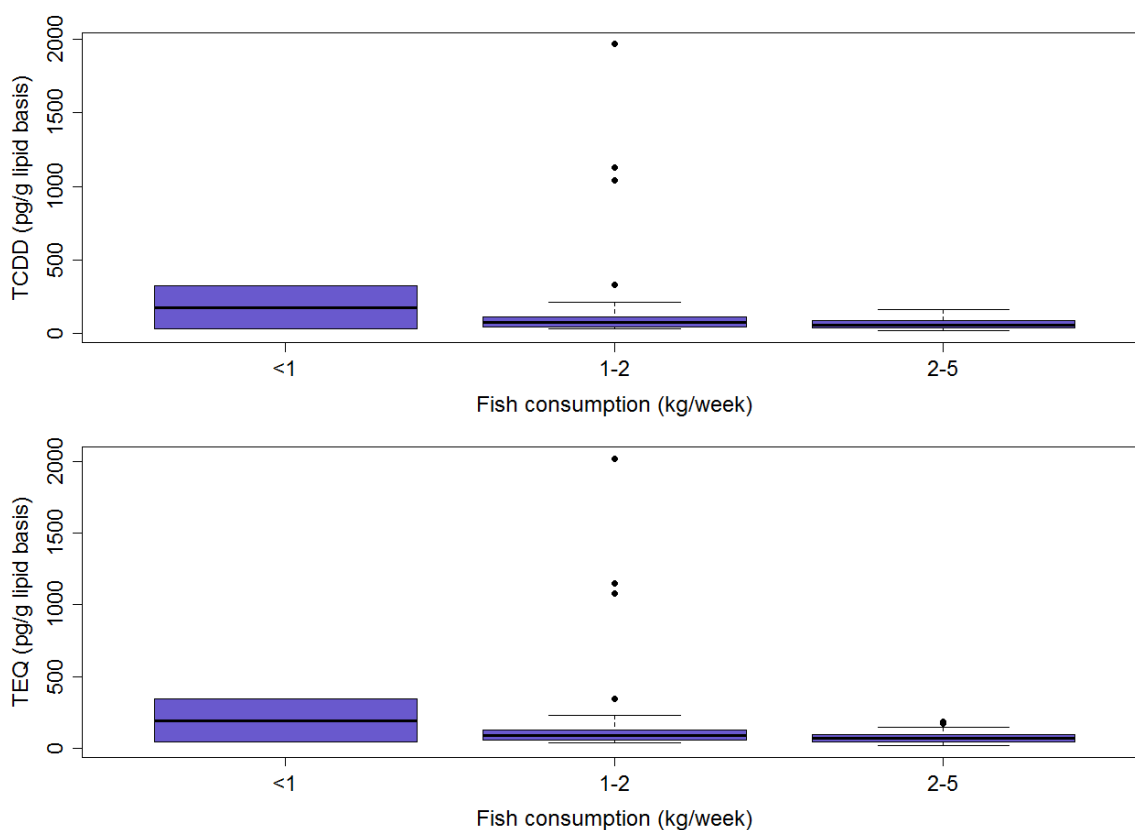
Figure 3.10 Locations of fishing sources and blood serum TCDD and TEQ (pg/g [ppt], lipid basis) of individuals in Bien Hoa, November 2010.



3.3.2.5 The Effect of the Amount of Fish Consumed

Serum dioxin levels were expected to be higher in individuals consuming greater amounts of fish from the Bien Hoa Airbase and its vicinities. A Kruskal Wallis test was carried out to compare TCDD and TEQ concentrations in serum samples between individuals consuming less than 1 kg of fish per week, 1 to 2 kg/week, and 2-5 kg/week (Figure 3.11). No statistically significant difference in TCDD and TEQ concentrations was found between individuals consuming different amounts of fish ($p= 0.3350$). A similar result was observed when TEQ levels were tested ($p= 0.3602$).

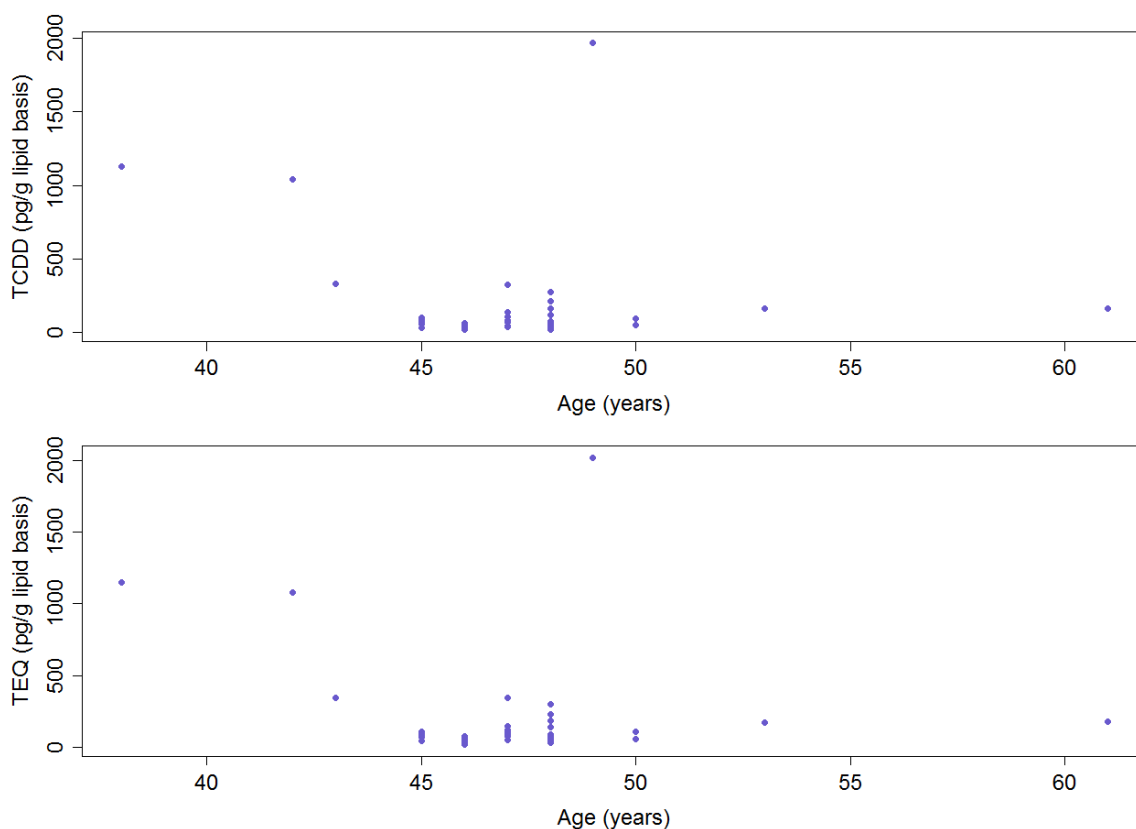
Figure 3.11 The amount of fish consumed per week and blood serum TCDD and TEQ (pg/g [ppt], lipid basis) in individuals from Bien Hoa, November 2010.



3.3.2.6 Age-related Effects

If the source of dioxin is removed from the exposure pathway, concentrations decrease over time. On the other hand, continued consumption of dioxin contaminated food may result in an increase in concentrations over time. A Spearman's correlation test was carried out to test if TCDD and TEQ concentrations vary with age for individuals sampled in Bien Hoa in 2010. A statistically significant correlation was not observed between age of an individual and their serum TCDD or serum TEQ concentration ($p_{TCDD} = 0.8652$; $p_{TEQ} = 0.9232$) (Figure 3.12).

Figure 3.12 Age versus blood serum TCDD and TEQ (pg/g [ppt], lipid basis) in individuals from Bien Hoa, November 2010.



3.3.3 Summary of Blood Data

The typical range of TCDD in the general population of industrialized countries has been reported as 3 to 7 pg/g (lipid basis) (ATSDR 1998). ATSDR also indicated that TCDD in human blood rarely exceeds 10 pg/g and that typically, lower levels of this contaminant are recorded in less industrialized countries. In serum samples analysed at Bien Hoa Airbase, TCDD concentrations were all higher than 10 pg/g. The minimum TCDD concentration recorded in Bien Hoa (2010) is 13.7 pg/g; the maximum is 1,970 pg/g; and the median is 67.8 pg/g. All but one serum sample exceeded the WHO 1998 standard of 30 ppt, clearly indicating the penetration of Agent Orange dioxin into the aquatic ecosystem and food chain.

Potential predictors of high serum dioxin content were tested through a series of statistical tests. The results indicated a statistically significant difference between serum dioxin levels and the location of fishing activities. Individuals who consume fish caught exclusively inside the Bien Hoa Airbase exhibited higher average TCDD and TEQ values compared to those who consume fish caught from both inside and outside the Airbase, and compared to those who fish exclusively outside the Airbase. Statistically significant gender- and age-related effects on serum dioxin levels were not discovered. The amount of fish consumed per week, the length of employment in the Airbase, and the length of residence in the Bien Hoa area also did not affect serum dioxin levels.

This study reports the percent TCDD present in the TEQ as the marker for Agent Orange exposure given that it is the only dioxin/furan congener that was a contaminant in Agent Orange. TCDD is considered the most toxic dioxin/furan congener, and has a multiplier of "1" when calculating WHO 2005 TEQs.

Where the percentage of TCDD in the TEQ is low, there are several other dioxin and furan congeners that are primary contributors to TEQ calculations for human blood samples in this study. These include 1,2,3,7,8-PCDD (TEF = 1), 2,3,4,7,8-PCDF (TEF = 0.3), 2,3,7,8-TCDF and all hexa-dioxins and furans (TEF = 0.1). Note that although OCDD concentrations are quite high, the TEF is very low (0.0003), and the contribution of OCDD to TEQ is consequently low.

In samples where penta- and hexa-dioxins and furans contribute more to TEQ, sources of contamination may include biphenyls, PCBs, pesticides, or incineration. Polychlorinated dibenzo-P-dioxins and furans (PCDDs and PCDFs) are mainly the by-products of industrial processes (such as metallurgical processing, bleaching of paper pulp, and the manufacturing of some herbicides and pesticides), but they can also result from natural processes like volcanic eruptions and forest fires (Srogi 2008). Waste incineration, particularly if combustion is incomplete, is among the largest contributors to the release of PCDDs and PCDFs into the environment. Consumption of food is considered as the major source of non-occupational human exposure to PCDD/Fs with foodstuffs from animal origin accounting for more than 90% of the human body burden, with meat, dairy and fish products being the main contributors (Srogi 2008). Other potential dioxin sources in Bien Hoa need to be determined and quantified in order to verify the total dioxin load to the environment and human population.

3.4 BREAST MILK

3.4.1 Results and Discussion

Dioxins and furans were analyzed in human breast milk collected from a total of 22 female donors in Bien Hoa in 2010. A majority of the women (n=18) were from the Trung Dung Commune, located to the south of the Airbase; others were from Tan Phong (n=2), Tan Tien (n=1), and Hoa An (n=1). Breast milk samples were not collected and analyzed during previous Hatfield/10-80/VRTC field programs in Bien Hoa. All milk TCDD/TEQ data are provided on a lipid-normalized basis.

Of the 22 breast milk donors, twelve were breastfeeding their first infant (primiparous females), eight were feeding their 2nd infant, and two were with their 3rd infant (Table 3.11).

A milk sample (10VNBH803) collected from a mother in Tan Phong Ward (inside the Airbase) exhibited elevated TCDD (30.3 ppt) and TEQ (39.6 ppt) levels relative to all other samples collected in 2010. TCDD contributed 76.5% of TEQ, indicating Agent Orange as the likely main contributor to dioxin loading. This donor is known to have consumed fish from 'Gate 2 Lake' and 'Z1 Lake' on numerous occasions in the past, where high dioxin concentrations were recorded in Tilapia sampled in 2010.

Milk samples collected from two donors in Trung Dung Ward to the south of the Airbase also showed elevated dioxin concentrations. Sample 10VNBH804 exhibited a high TCDD of 22.5 ppt and a TEQ of 28.6 ppt; TCDD accounted for a large proportion (78.7%) of the contamination. Sample 10VNBH814 exhibited a TCDD level of 13.8 ppt and TEQ of 31.8 ppt. TCDD comprised 43.4% of the TEQ, indicating that other sources of dioxins contribute to overall contamination of this sample.

Fifteen (15) breast milk samples collected during the 2010 sampling program exhibited TCDD concentrations below 4 pg/g. Proportions of TCDD to the TEQ concentration in these samples were all below 50% (except 10VNBH808). Sample 10VNBH821 collected from Trung Dung Ward had a low proportion of TCDD in the TEQ concentration (12.2%). These results indicate that Agent Orange is not the sole source of dioxin contamination in breast milk sampled from this area. Other dioxin congeners also contribute to total TEQ values.

Table 3.10 Concentrations of polychlorinated dibenzo-*p*-dioxins (PCDD) and polychlorinated dibenzofurans (PCDF) in human breast milk from districts near the Bien Hoa Airbase (pg/g [ppt], lipid basis), Viet Nam, November, 2010.

Sample ID	Age	PCDD (pg/g lipid basis)						PCDF (pg/g lipid basis)						% Lipid	TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)
		2,3,7,8-TCDD	Total T4CDD	Total P5CDD	Total H6CDD	Total H7CDD	Total O8CDD	2,3,7,8-TCDF	Total T4CDF	Total P5CDF	Total H6CDF	Total H7CDF	Total O8CDF				
10VNBH800	34	8.21	8.21	2	6.17	7.12	44.7	0.584	0.699	3.79	8.95	4.03	0.146	9.61	13.4	12.8	64.1
10VNBH801	27	2.39	2.39	1.74	7.39	10	113	NDR 0.456	0.765	3.89	13.9	8.79	<0.306	6.14	8.22	7.54	31.7
10VNBH802	30	1.48	1.48	2.01	7.17	7.82	44.7	0.564	0.722	4.02	10.4	5.09	0.229	5.7	7.24	6.53	22.7
10VNBH804	21	22.5	22.5	2.7	6.53	14.1	106	NDR 0.917	13.4	3.74	13.3	1.32	<0.479	4.25	29.3	28.6	78.7
10VNBH805 ¹	39	< 12.3	NC	NC	NC	NC	70.3	< 6.74	NC	NC	NC	NC	<0.22	3.68	14.3	13.7	NC
10VNBH806 ¹	21	< 0.246	NC	NC	NC	NC	48.3	< 2.33	NC	NC	NC	NC	<0.246	3.58	1.86	1.55	NC
10VNBH807	28	2.94	2.94	5.07	16.3	17.3	153	< 0.787	0.812	5.99	11.6	8.88	<0.482	1.97	14.2	13	22.6
10VNBH808	28	3.11	3.11	< 0.434	2.87	8.17	54.2	NDR 0.837	0.518	3.39	7.61	< 0.558	0.398	2.51	6.25	5.58	55.7
10VNBH809	25	2.45	2.45	2.27	2.52	6.89	49.2	0.732	< 0.252	3.91	9.79	5.78	<0.252	3.96	8.16	7.39	33.2
10VNBH810	29	9.85	9.85	2.4	6.43	6.03	35.2	NDR 1.17	< 0.705	< 0.705	7.91	1.02	<0.705	1.96	14.1	14	70.4
10VNBH811	24	NDR 1.64	< 0.359	1.14	6.94	20.5	77.5	NDR 0.629	0.729	2.02	6.54	< 0.325	0.431	6.04	3.88	3.49	NC
10VNBH814	27	13.8	13.8	13.1	29.8	10.4	116	1.01	0.781	< 0.344	15.7	4.91	0.781	3.46	31.8	31.8	43.4
10VNBH816 ¹	23	1.37	NC	NC	NC	NC	35.4	< 5.38	NC	NC	NC	NC	<0.417	3.64	6.58	5.86	23.4
10VNBH817 ¹	27	< 0.815	NC	NC	NC	NC	47.5	< 8.71	NC	NC	NC	NC	<1.51	1.24	3.23	2.99	NC
10VNBH818	34	10.2	10.2	1.74	3.94	5.61	30	NDR 0.744	0.992	1.86	5.09	2.18	<0.263	4.03	13.9	13.5	75.6
10VNBH819	38	1.72	1.72	2.21	5.76	7.48	60.8	NDR 0.592	< 0.425	2.74	7	4.14	<0.425	1.86	6.79	6.25	27.5
10VNBH820	25	3.2	3.2	1.17	6.22	12.9	111	0.361	0.509	2.55	8.68	6.96	<0.168	4.7	7.19	6.78	47.2
10VNBH821	24	0.773	0.773	1.87	11.2	18.2	94.9	0.244	0.378	3.12	13.9	6.09	0.218	11.9	6.92	6.32	12.2
10VNBH803	29	30.3	30.3	4.25	28.7	113	182	NDR 0.437	0.714	4.84	9.88	0.873	<0.314	2.52	40.4	39.6	76.5
10VNBH812	26	8.99	8.99	1.67	5.72	7.88	63.2	NDR 0.818	1.04	3.08	5.87	3.57	<0.312	2.69	13.1	12.7	70.8
10VNBH813	34	2.27	2.27	1.46	5.51	6.68	58.4	0.859	0.978	2.81	6.34	4.84	<0.274	4.19	6.33	5.87	38.7
10VNBH815	28	2.31	2.31	3.11	10.1	23	104	NDR 0.854	0.552	5.22	14.8	8.14	<0.397	1.99	10.9	9.83	23.5

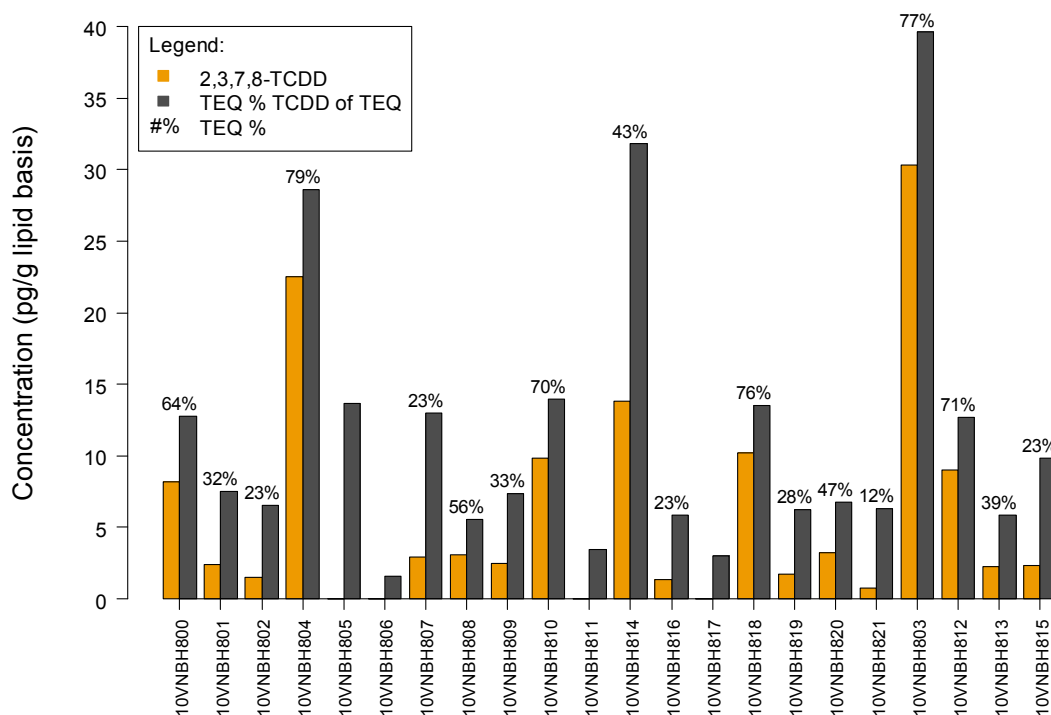
¹ Additional clean up was not successful; therefore, only the 2,3,7,8-TCDD and -TCDF values were reported with confidence. As the reported congeners have non-zero TEFs, the TEQ for each sample remains unaffected.

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

NDR = Peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND.

NC = Not calculated.

Figure 3.13 TCDD and Total TEQ (pg/g [ppt], lipid basis) in human breast milk for Bien Hoa Airbase and Bien Hoa City, November 2010.

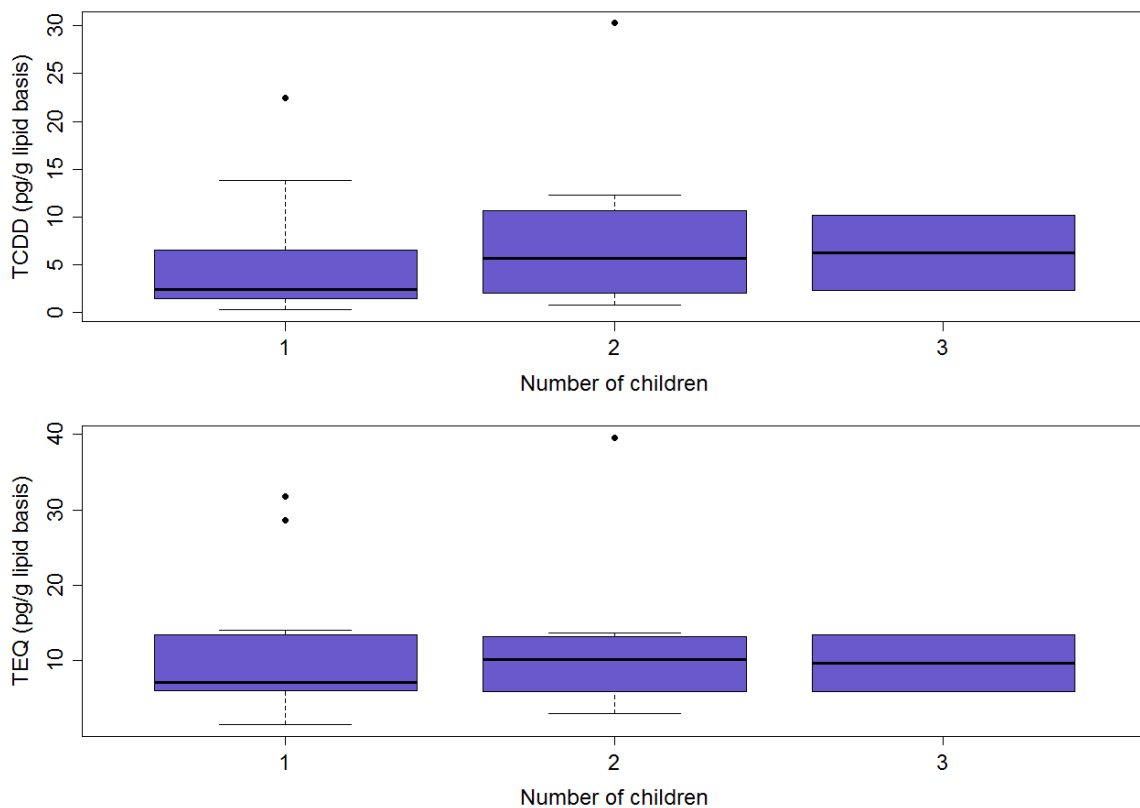


3.4.2 Statistical Analysis of Breast Milk Data

3.4.2.1 The Effect of Multiple Child Births

There is evidence that the first child is exposed to higher concentrations of PCDDs/Fs than second and later children (Fürst *et al.* 1989). Whether the number of children affects the mother's TCDD and TEQ concentrations (pg/g lipid basis) was statistically tested. No significant differences in the TCDD and TEQ were found between mothers who were nursing their first, second, and third child in Bien Hoa area ($p_{TCDD} = 0.5182$; $p_{TEQ} = 0.929$) (Figure 3.14)

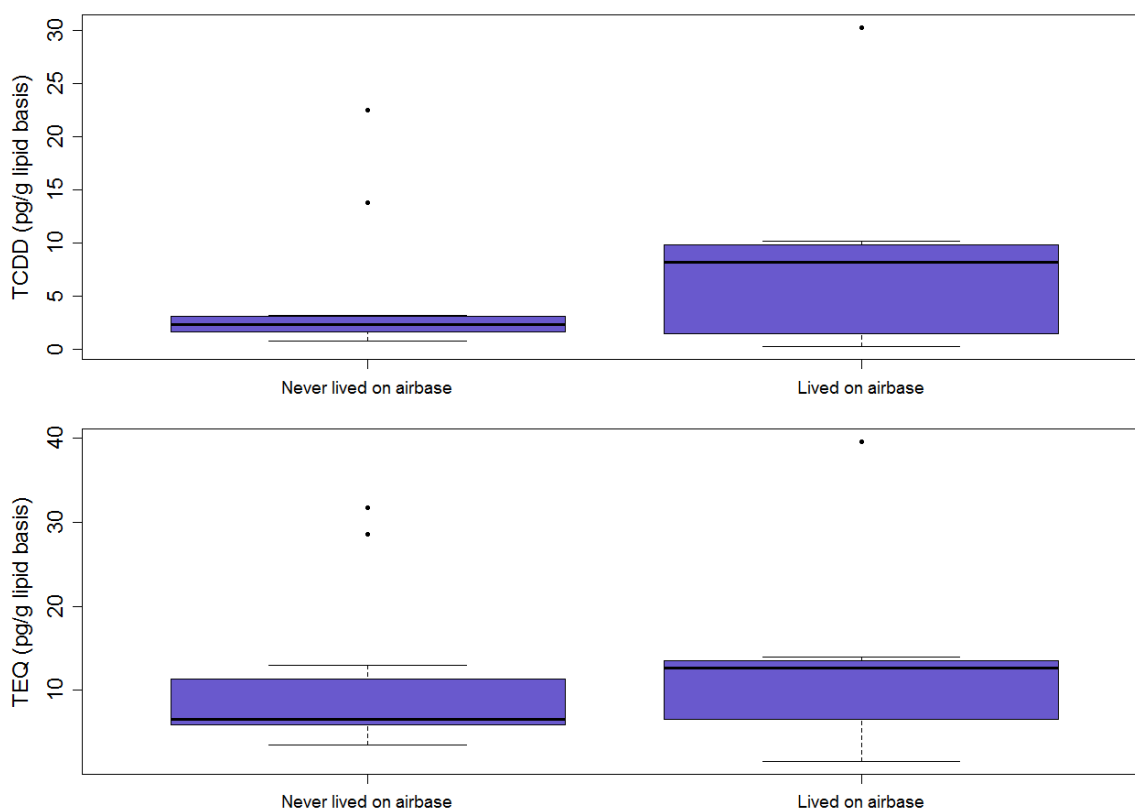
Figure 3.14 Breast milk TCDD and TEQ (pg/g [ppt], lipid basis) for mothers nursing their first, second and third infant in Bien Hoa, November 2010.



3.4.2.2 The Effect of Residing Inside the Airbase

Given the high dioxin concentrations observed inside the Bien Hoa Airbase, it is assumed that women who have lived inside the Airbase exhibit higher TEQ concentrations than women who have not, because they would likely be eating more fish from the lakes on the Airbase. Breast milk TCDD and TEQ concentrations were compared between women who have lived on the Airbase and those who have not (Figure 3.15). No statistically significant difference in TCDD and TEQ were found between the two groups ($p_{TCDD} = 0.6242$; $p_{TEQ} = 0.9700$).

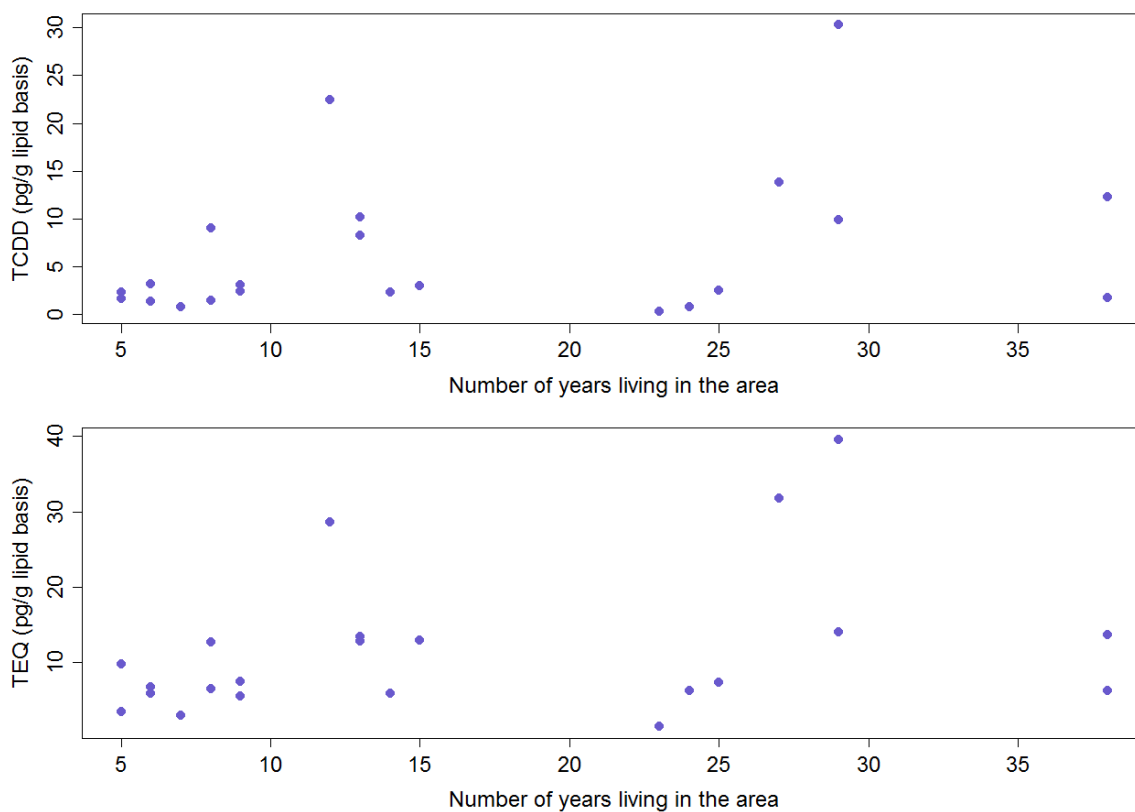
Figure 3.15 Breast milk TCDD and TEQ (pg/g [ppt], lipid basis) for mothers who have resided inside the Bien Hoa Airbase and those who have not, November 2010.



3.4.2.3 The Effect of the Length of Stay in the Bien Hoa Airbase and Its Vicinity

A statistical test was carried out to identify a possible correlation between the length of stay in the Bien Hoa area and the TCDD and TEQ concentration in breast milk (Figure 3.16). No statistically significant correlation was observed among the two variables for TCDD ($p=0.3044$) and TEQ concentrations ($p=0.2099$) and the length of stay, indicating that the length of residence at Bien Hoa Airbase and its vicinity does not affect dioxin levels in breast milk.

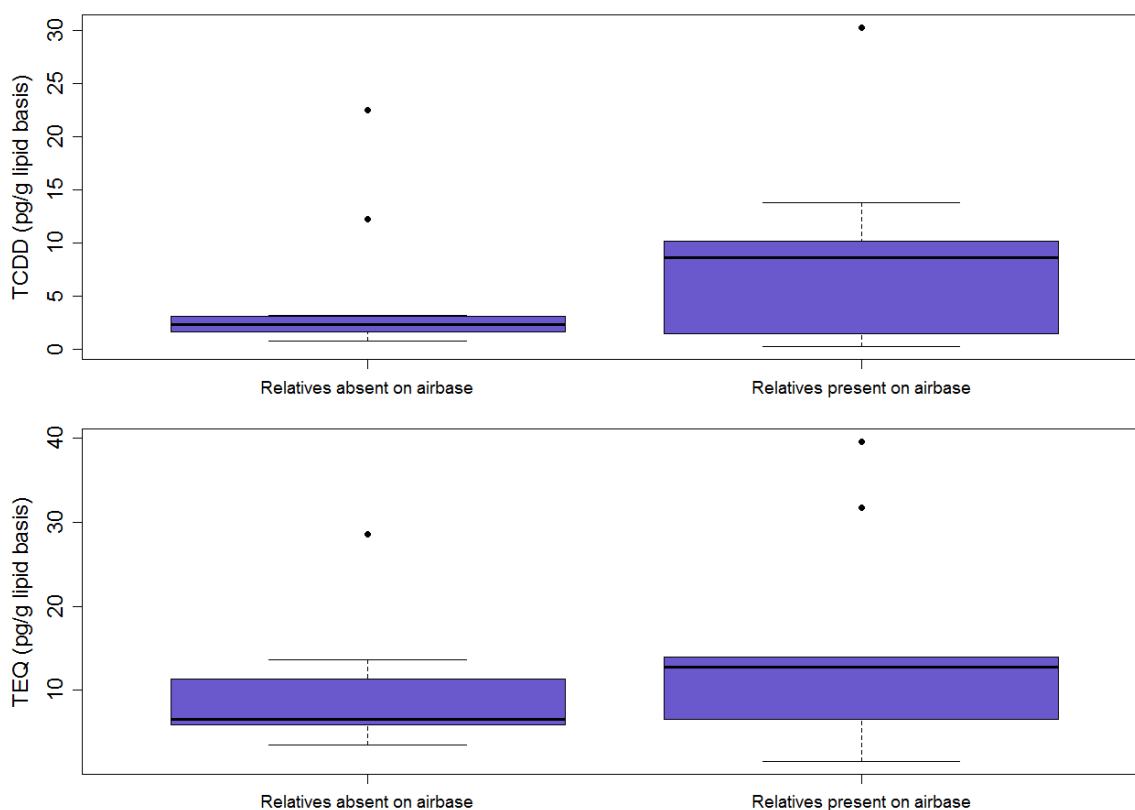
Figure 3.16 Relationship between the length of stay at the Bien Hoa Airbase and its vicinity and breast milk TCDD and TEQ (pg/g [ppt], lipid basis), November 2010.



3.4.2.4 Effect of Relatives on the Airbase

Higher breast milk dioxin levels are expected in women who have relatives living inside the Airbase, compared to those who do not, as they may receive fish, vegetables, and other aquatic plants/animals cultivated inside the Airbase, which may be contaminated with dioxins. Breast milk TCDD and TEQ concentrations were statistically tested for differences between women who have relatives living inside the Airbase and women who do not. No significant differences were found in TCDD or TEQ concentrations ($p_{TCDD}=0.4424$ and $p_{TEQ}=0.5286$) between the two groups (Figure 3.17).

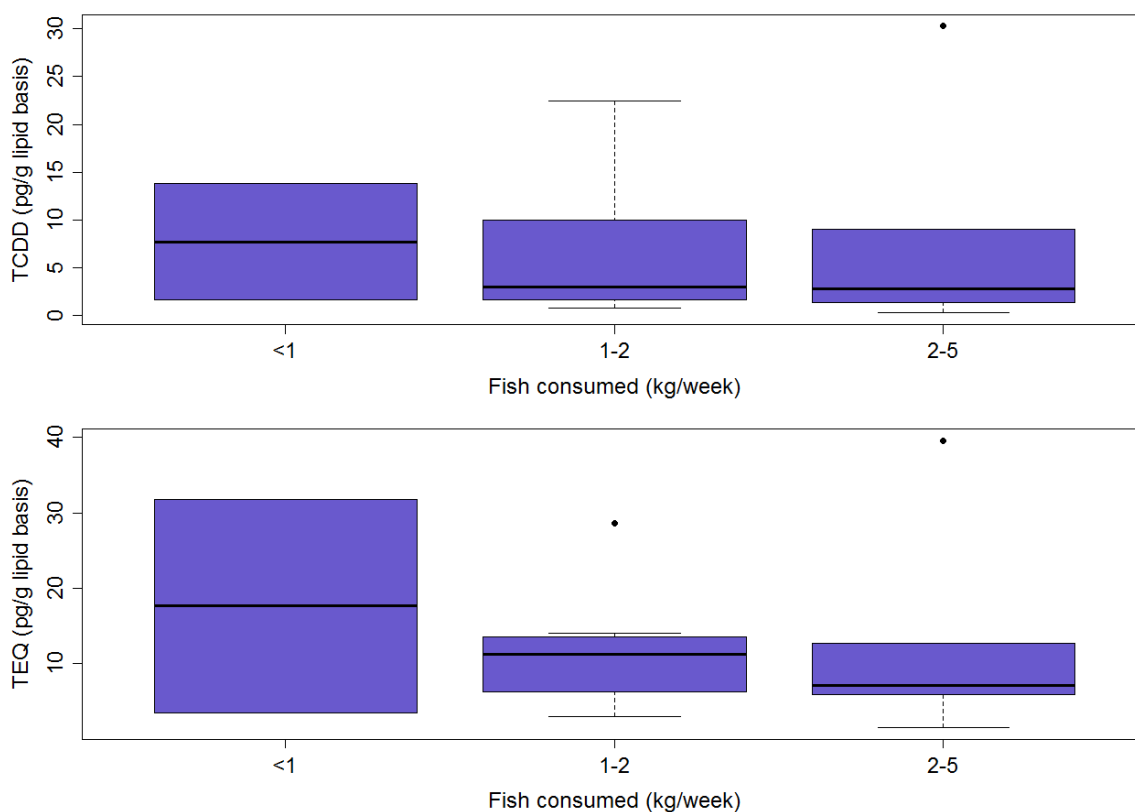
Figure 3.17 Breast milk TCDD and TEQ (pg/g [ppt], lipid basis) in women with and without relatives living inside the Bien Hoa Airbase, November 2010.



3.4.2.5 The Effect of the Amount of Fish Consumed

The present study found extremely high dioxin concentrations in Tilapia sampled from inside the Bien Hoa Airbase, and in lakes and ponds immediately to the south of the Airbase (see Section 3.2). An ANOVA test was carried out to compare TCDD and TEQ concentrations in breast milk samples between women who consume less than 1 kg of fish per week, 1 to 2 kg/week, and 2-5 kg/week (Figure 3.18). A statistically significant difference was not found in TCDD concentrations and the amount of fish consumed ($p=0.8949$). A similar result was observed when TEQ levels were tested ($p=0.8726$).

Figure 3.18 The amount of fish consumed per week and breast milk TCDD and TEQ (pg/g [ppt], lipid basis) in women in Bien Hoa, November 2010.



3.4.3 Summary of Bien Hoa Breast Milk Data

The WHO acceptable standards (1 to 4 pg TEQ/kg bw/day) cover the range of established Tolerable Daily Intake PCDD/F exposures for several countries (as presented in Table 1.7). In Canada, the TDI has been reduced to 2.3 pg TEQ/kg bw/d (Health Canada 2005) from 10 pg TEQ/kg bw/d. The most highly exposed part of the population is breastfed infants, where exposure to PCDDs and PCDFs via ingestion can be higher, on a body weight basis, than during other periods in a person's life (Lakind 2007).

To assess the TEQ levels in breast milk recorded during the Bien Hoa 2010 Study, the Average Daily Intake (ADI) was calculated based on recommended parameters established by the WHO (WHO/EURO 1989). These parameters assume an infant weight of 5 kg, milk consumption by the infant of 700 ml/d, and a percent milk fat of 3.5%. Table 3.11 presents these calculations and the ADI based on actual milk fat (lipid) percentages by donor.

Utilizing the WHO parameters, all individual ADI values from the Bien Hoa study exceeded the 4 pg TEQ/kg bw/d WHO standard. The ADI was lowest with sample 10VNBH817, a mother from Trung Dung Ward, who was feeding her second child. The ADI was 5 pg TEQ/kg bw/d based on the actual lipid percent, and 14.7 pg TEQ/kg bw/d when the 3.5% WHO parameter was used. As reported in Section 1.4.4, breastfed babies often have a daily dioxin intake 1- to 2- times greater than adults, and can be as high as 35 pg I-TEQ/g milk fat in industrialized countries. The Tan Tien sample (10VNBH813) and samples 10VNBH809, 10VNBH816 and 10VNBH820 from Trung Dung Ward fall within this exposure level.

The ADI calculated with actual milk fat (lipid) for a mother from Trung Dung (10VNBH800) is the highest of those sampled in Bien Hoa in 2010 (172 pg TEQ/kg bw/d), followed by a sample from a young mother feeding her first child residing in the same ward (10VNBH804: 170 pg TEQ/kg bw/d). ADIs greater than 100 pg TEQ/kg bw/d were also observed for two other residents of Trung Dung and another from Tan Phong.

A series of statistical analyses were carried out to identify possible relationships between breast milk TCDD and TEQ concentrations, and historical, locational and consumption characteristics of sampled women. The analyses did not reveal statistically significant (at $\alpha=0.01$) determinations of milk dioxin levels. An increase in sample size may yield different results.

Lakind (2007) reports that there appears to be a decline in global levels of PCDDs/Fs in human milk from the 1970s to 2005. However, the question of whether the presence of PCDDs/Fs in milk is from the lifetime accumulation of PCDDs/Fs in adipose tissue or current diet (or a combination of both) remains unanswered. There is evidence that the first child is exposed to higher concentrations of PCDDs/Fs than second and later children (Fürst *et al.* 1989).

Table 3.11 Average daily intake¹ (pg TEQ/kg bw/d) of TCDD and Total-TEQ by infants consuming human breast milk² collected from females (first, second or third child), Bien Hoa 2010.

Sample ID	Age	Infant # Currently Breast- feeding	% Lipid	2,3,7,8- TCDD	TEQ (WHO 2005) ND=1/2DL	Average Daily Intake			
						TCDD (actual lipid)	T-TEQ (actual lipid)	TCDD (3.5% lipid)	T-TEQ (3.5% lipid)
10VNBH800	34	2nd	9.61	8.21	12.8	110.5	172	40.2	62.7
10VNBH801	27	2nd	6.14	2.39	7.54	20.5	64.8	11.7	36.9
10VNBH802	30	1st	5.7	1.48	6.53	11.8	52	7.3	32.0
10VNBH804	21	1st	4.25	22.5	28.6	133.9	170	110.3	140.1
10VNBH805	38	2nd	3.68	< 12.3	13.7	NC	71	NC	67.1
10VNBH806	23	1st	3.58	< 0.246	1.55	NC	8	NC	7.6
10VNBH807	28	1st	1.97	2.94	13	8.1	36	14.4	63.7
10VNBH808	28	2nd	2.51	3.11	5.58	10.9	20	15.2	27.3
10VNBH809	25	1st	3.96	2.45	7.39	13.6	41	12.0	36.2
10VNBH810	29	1st	1.96	9.85	14	27.0	38	48.3	68.6
10VNBH811	24	1st	6.04	NDR 1.64	3.49	NC	30	NC	17.1
10VNBH814	27	1st	3.46	13.8	31.8	66.8	154	67.6	155.8
10VNBH816	23	1st	3.64	1.37	5.86	7.0	30	6.7	28.7
10VNBH817	27	2nd	1.24	< 0.815	2.99	NC	5	NC	14.7
10VNBH818	34	3rd	4.03	10.2	13.5	57.5	76	50.0	66.2
10VNBH819	38	2nd	1.86	1.72	6.25	4.5	16	8.4	30.6
10VNBH820	25	1st	4.7	3.2	6.78	21.1	45	15.7	33.2
10VNBH821	24	1st	11.9	0.773	6.32	12.9	105	3.8	31.0
10VNBH803	29	2nd	2.52	30.3	39.6	106.9	140	148.5	194.0
10VNBH812	26	2nd	2.69	8.99	12.7	33.9	48	44.1	62.2
10VNBH813	34	3rd	4.19	2.27	5.87	13.3	34	11.1	28.8
10VNBH815	28	1st	1.99	2.31	9.83	6.4	27	11.3	48.2

¹ Average daily intake = (volume of milk per day in ml)x(% lipid in milk/100)x(concentration of chemical in pg/g)/(infant weight in kg).

² Average daily intake via human milk based on an infant body weight of 5 kg and consuming 700 ml of milk per day (WHO/EURO 1989).

ND = Not detected; for "Total TEQ" calculations, if ND, 1/2 detection level was used.

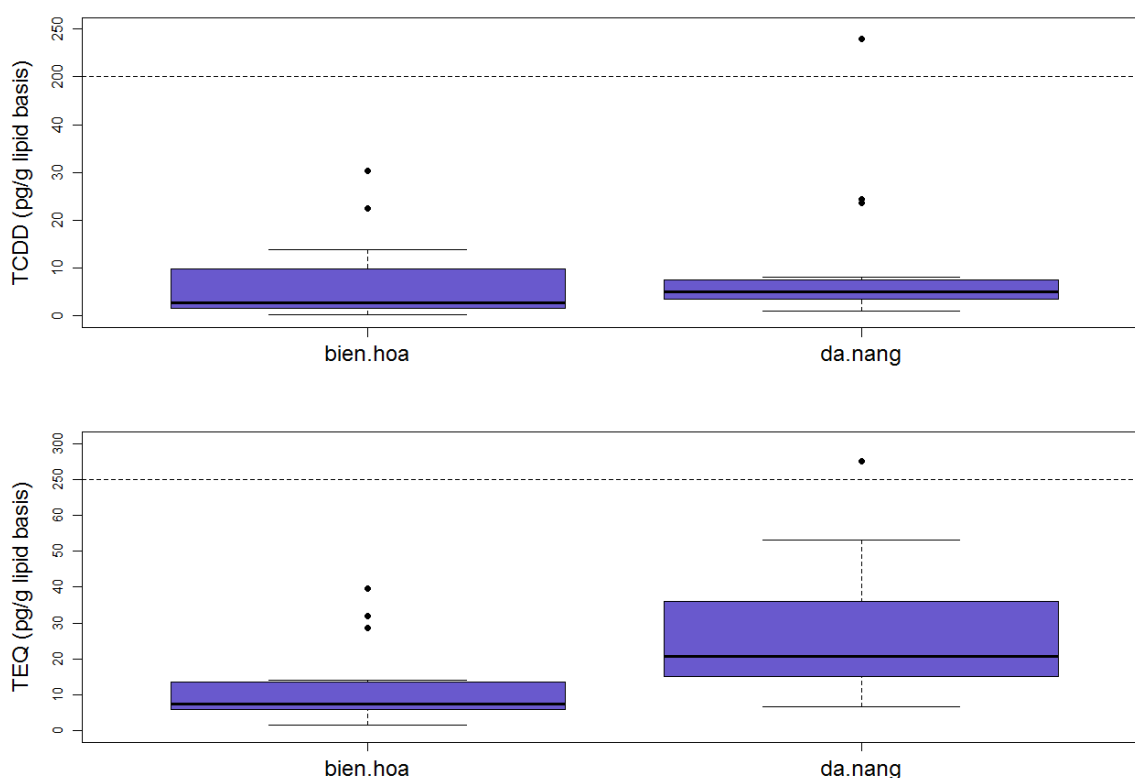
NDR = Peak detected but did not meet quantification criteria; for 'Total TEQ' calculations, NDR was treated as ND.

NC = Not calculated.

3.4.4 Comparison with Da Nang Results (2007 and 2009)

Dioxins and furans were analysed in human breast milk collected from a total of 14 female donors in Da Nang during the Hatfield/Office 33 (2009) study. On average, the TCDD concentrations in breast milk samples collected in Da Nang were higher than samples analysed in Bien Hoa (2010); samples from Bien Hoa exhibited a mean TCDD concentration of 6.49 ppt with a standard deviation of 7.71 ppt, while samples from Da Nang exhibited a mean TCDD of 22.24 ppt with a standard deviation of 58.46 ppt. Distribution of TCDD and TEQ concentrations in Da Nang and Bien Hoa breast milk samples are shown in Figure 3.19.

Figure 3.19 Box plot of breast milk TCDD and TEQ (pg/g [ppt], lipid basis) in Bien Hoa (2010) and Da Nang (2007 and 2009).



A milk sample collected from a relocated Sen Lake Worker from Da Nang exhibited very high TCDD (232 ppt) and TEQ (263 ppt) values; the highest TCDD and TEQ values observed in Bien Hoa are 30.3 ppt and 39.6 ppt, respectively. The ADI values calculated based on actual milk fat (lipid) percentages of donors exceeded the WHO acceptable standard (1-4 pg TEQ/kg bw/d) for all donors from the Da Nang 2009 Study (Hatfield/Office 33 2009) and the Bien Hoa 2010 Study. Five donors from Bien Hoa had ADI values exceeding 100 pg TEQ/kg bw/d, the highest recorded being 172 pg TEQ/kg bw/d. In Da Nang, nine (9) of the 15 breast milk samples analyzed exhibited ADI values exceeding 100 pg TEQ/kg bw/d, and the highest average daily intake was as high as 2,320 pg TEQ/kg bw/d for the same relocated Sen Lake worker.

3.5 QA/QC

3.5.1 Environmental Samples

Lab QA/QC

AXYS performed a number of duplicate and replicate dioxin and furan analyses as part of the QA/QC for this project (Table 3.12). In most cases, soil, sediment and fish tissue duplicate samples were in close agreement, and were within acceptable levels of variability. A relatively high variability in TCDD (RPD=20.5%) observed in sample 08VNBH167 may be attributed to a slight variation in substrate composition of the soil sample.

Field QA/QC

QA/QC replicate samples were collected by Hatfield throughout the Airbase. Soil replicates were collected at the Pacer Ivy Area, Z1 Area, and the northeast perimeter; sediment replicates were collected from Z1 Area; and fish tissue replicates were collected for Tilapia whole fish sampled in Pacer Ivy Lake. The difference between replicates was calculated as a relative percent difference (RPD). RPDs calculated for TCDD were greater than 20% for soil collected at the Pacer Ivy Area (10VNBH230) and Z1 Area (10VNBH428). A high variability in TCDD in these two samples could be attributed to soil heterogeneity. All other replicates had RPDs below 20% for both TCDD and TEQ indicating good homogenization of samples, and a high level of confidence in lab analysis.

3.5.2 Rinseate Water

Two samples were analyzed from rinseate water used to clean sampling equipment used in this study (Table 3.12). One sample, collected at the middle of the November 2010 Airbase sampling program (10VNBH706) did not have detectable levels of dioxins and furans. The second sample, collected at the end of the sampling program (10VNBH712), had similar results indicating no cross-contamination between sites.



Source: Hatfield Consultants

Table 3.12 AXYS Lab and Hatfield Consultants QA/QC for dioxin and furan analyses, Bien Hoa, Viet Nam, November 2010.

Sample ID	Location	Media	Depth (bgs) ⁷	2,3,7,8-	1,2,3,7,8-	1,2,3,4,7,	1,2,3,6,7,	1,2,3,7,8,	1,2,3,4,6,7	OCDD	2,3,7,8-	2,3,7,8-	1,2,3,7,8-	2,3,4,7,8-	1,2,3,4,7,	1,2,3,6,7,	1,2,3,7,8,	2,3,4,6,7,	1,2,3,4,6,7	1,2,3,4,7,8,	OCDF
				TCDD	PeCDD	8-HxCDD	8-HxCDD	9-HxCDD	,8-HpCDD		TCDF	TCDF (C) ⁸	PeCDF	PeCDF	8-HxCDF	8-HxCDF	9-HxCDF	8-HxCDF	,8-HpCDF	9-HpCDF	
Field Duplicates																					
10VNBH704	Pacer Ivv Area	Soil	0-15	61.9	< 2.96	< 4.33	NDR 4.52	< 4.33	NDR 25.3	168	9.89	NDR 8.30	< 3.85	< 3.85	< 4.41	< 4.41	< 4.41	< 4.41	< 2.98	< 2.98	NDR 4.17
10VNBH230				83.9	NDR 1.99	NDR 1.71	NDR 3.74	NDR 3.09	34	326	13.4	11.7	< 0.975	1.17	< 0.975	< 0.975	< 0.975	< 0.975	NDR 7.78	< 0.975	NDR 23.7
RPD (%)^{1,2}				30.2	NC	NC	NC	NC	NC	64.0	30.1	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
10VNBH705	Pacer Ivv Area	Soil	30-60	54700	240	24.7	199	102	547	1390	1790	912	NDR 16.7	21.2	NDR 21.5	NDR 6.02	< 4.02	NDR 10.9	88.6	NDR 4.35	58.1
10VNBH237-2				61400	252	NDR 21.8	176	92	557	1910	1530	798	NDR 22.7	NDR 21.6	NDR 18.0	7.88	< 5.30	6.46	77.5	< 4.79	53.7
RPD (%)^{1,2}				11.5	4.9	NC	12.3	10.3	1.8	31.5	15.7	13.3	NC	NC	NC	NC	NC	NC	13.4	NC	7.9
10VNBH708	Z1 Area	Sediment	0-20	26.1	< 4.31	< 5.20	< 5.20	< 5.20	NDR 21.1	265	NDR 5.38	< 5.58	< 4.27	< 4.27	< 3.36	< 3.36	< 3.36	< 3.36	8.45	< 3.90	10.5
10VNBH428				33.9	NDR 7.77	10.3	NDR 11.2	NDR 8.47	38.3	342	6.02	2.92	NDR 2.92	NDR 4.61	6.96	6.48	< 3.35	NDR 8.80	6.17	NDR 5.87	14.4
RPD (%)^{1,2}				26.0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	31.2	NC	31.3
Trip Blanks																					
10VNBH710	Trip Blank	Sand		NDR 0.0718	< 0.0495	< 0.0495	< 0.0495	< 0.0495	0.234	2.89	< 0.0495	< 0.0495	< 0.0495	< 0.0495	< 0.0495	< 0.0495	< 0.0495	< 0.0495	0.0668	< 0.0495	NDR
Laboratory Duplicates																					
08VNBH167	Z1 Area	Soil	0-10	985	11.1	2.59	19	NDR 11.9	126	921	48.3	33.9	< 2.17	< 2.17	NDR 2.11	1.08	< 0.898	NDR 1.00	19.1	NDR 1.26	24.4
08VNBH167 (Duplicate)				1210	15.1	4.94	20.5	12.7	156	1130	53.7	37.1	1.14	NDR 2.05	2.53	1.45	< 0.994	1.47	21.8	NDR 1.37	34.2
RPD (%)^{1,2}				20.5	30.5	62.4	7.6	NC	21.3	20.4	10.6	9.0	NC	NC	NC	29.2	NC	NC	13.2	NC	33.4
08VNBH144	Z1 Area	Soil	0-10	34	3.91	< 4.04	7.29	< 4.04	NDR 84.1	1140	< 3.83	< 3.83	< 2.43	2.69	4.35	< 2.94	< 2.94	< 2.94	NDR 18.6	4.77	57.1
08VNBH144 (Duplicate)				29.1	< 2.95	NDR 2.72	NDR 4.49	< 2.19	90.3	1260	< 2.43	< 2.43	< 3.05	< 3.05	< 3.99	< 3.99	< 3.99	< 3.99	NDR 14.9	< 3.15	66.1
RPD (%)^{1,2}				15.5	NC	NC	NC	NC	NC	10.0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	14.6
10VNBH426	Z1 Area	Soil	0-10	111	3.3	5.95	15.6	14	416	3470	10.8	5.19	1.24	NDR 1.90	4.91	2.78	NDR 0.384	2.78	32.6	2.18	58.7
10VNBH426 (Duplicate)				114	3.43	6	17.7	14.8	482	3860	6.84	4.54	1.49	2.33	4.63	2.87	NDR 0.400	3.04	36.9	2.73	67.1
RPD (%)^{1,2}				2.7	3.9	0.8	12.6	5.6	14.7	10.6	44.9	13.4	18.3	NC	5.9	3.2	NC	8.9	12.4	22.4	13.4
10VNBH229	Pacer Ivv Area	Soil	0-10	7.97	< 0.794	NDR 1.52	NDR 2.82	NDR 3.01	57.8	513	1.41	1.27	< 0.794	< 0.794	< 0.794	< 0.794	< 0.794	< 0.794	4.52	< 0.794	14.2
10VNBH229 (Duplicate)				NDR 5.16	< 0.873	NDR 1.33	2.47	< 0.897	55.3	469	< 3.12	< 14.4	< 4.01	< 4.01	< 1.40	< 1.40	< 1.40	< 1.40	< 4.86	< 4.86	NDR 6.20
RPD (%)^{1,2}				NC	NC	NC	NC	NC	4.4	9.0	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
10VNBH235	Pacer Ivv Area	Soil	0-10	2.76	0.382	NDR 0.559	0.971	1.25	20.7	247	0.677	0.334	0.192	0.233	0.384	NDR 0.212	0.138	0.212	2.41	NDR 0.189	6.76
10VNBH235 (Duplicate)				2.98	0.425	0.471	1.1	1.45	20.1	261	0.827	0.352	0.186	0.267	0.339	0.315	< 0.0873	NDR 0.355	2.81	0.234	7.58
RPD (%)^{1,2}				7.7	10.7	NC	12.5	14.8	2.9	5.5	19.9	5.2	3.2	13.6	12.4	NC	NC	NC	15.3	NC	11.4
10VNBH521	Pacer Ivv Lake	Fish	Whole Fish	618	3.22	0.803	3.15	1.2	3.68	8.69	3.76	< 0.0547	0.323	NDR 0.108	< 0.0867	< 0.0867	< 0.0867	0.285	< 0.160	0.333	2.81
10VNBH521 (Duplicate)				621	3.11	0.727	3.27	1.06	3.77	8.64	3.86	NDR 0.121	0.278	0.0869	< 0.0819	< 0.0819	< 0.0819	0.217	< 0.0865	0.318	2.91
RPD (%)^{1,2}				0.5	3.5	9.9	3.7	12.4	2.4	0.6	2.6	NC	15.0	NC	NC	NC	NC	27.1	NC	4.6	3.5
10VNBH208	Northeast Perimeter	Soil	0-10	996	25.6	3.47	11.3	8.86	131	1010	130	85.3	3.27	3.86	4	1.87	0.512	1.43	29.4	1.9	48.3
10VNBH208 (Duplicate)				1110	27.9	3.94	12.6	10.5	151	1170	145	99.7	3.61	4.44	4.72	2.08	0.511	1.79	36	1.98	61.8
RPD (%)^{1,2}				10.8	8.6	12.7	10.9	16.9	14.2	14.7	10.9	15.6	9.9	14.0	16.5	10.6	0.2	22.4	20.2	4.1	24.5
Equipment Rinseates³																					
Sample ID	Location	Media	Depth (bgs)	PCDD (pg/L)							PCDF (pg/L)							TEQ (WHO 1998) ND=1/2DL	TEQ (WHO 2005) ND=1/2DL	TCDD as % of TEQ (2005)	
				2,3,7,8-TCDD	Total T4CDD	Total T5CDD	Total T6CDD	Total T7CDD	OCDD	2,3,7,8-TCDF	Total T4CDF	Total T5CDF	Total T6CDF	Total T7CDF	OCDF						
10VNBH706	Mid program rinseate	Water	-	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	3.63	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	< 0.962	1.63	1.52	NC
10VNBH712	End of program rinseate	Water	-	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	5.12	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	< 0.953	1.61	1.51	NC

¹ RPD = Relative Percent Difference.

² The RPDs which exceed the Project criteria (> 20%) are considered acceptable due to the low level concentrations and sample heterogeneity in the matrix.

³ 10VNBH706 and 10VNBH712 (equipment rinsates) are aqueous samples (pg/L). The concentrations in the equipment rinsate should be considered in analyzing the final results.

⁴ "<" = less than the detection limit; number following this symbol represents the detection limit.

⁵ NDR = peak detected but did not meet quantification criteria; number following this flag represents the estimated maximum possible concentration.

⁶ NC = Not calculated when NDR values of TCDD are considered "0" or concentrations are less than detection for RPDs.

⁷ bgs = below ground surface.

⁸ If 2,3,7,8 TCDF is detected on the primary column, the result must be confirmed on a second column. The 2,3,7,8 TCDF isomer cannot be uniquely resolved from its neighbouring isomers (i.e. 1249-, 2348-, and 2346-TCDF) if they are present; all four compounds appear as a single peak on the primary column. The 2,3,7,8 TCDF (C) confirmatory column only includes the 2,3,7,8 TCDF isomer. Only 2,3,7,8 TCDF (C) is considered herein to meet QA/QC limits.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The 2010 environmental and human studies at Bien Hoa Airbase and in surrounding communities have provided significant new information on the overall dioxin contamination issue in the Bien Hoa area. When combined with data collected in 2004-2005 and 2008 from the most highly contaminated areas in the Airbase (Hatfield/10-80 2006; Hatfield/VRTC 2009), we now have a better understanding of dioxin-contaminated areas, exposure pathways, and affected populations. A total of 258 environmental samples have been analyzed for dioxin/furan concentrations from Bien Hoa Airbase and Bien Hoa City since 2005, under studies conducted by Hatfield, Office 33, 10-80 Division and VRTC (Hatfield/10-80 2006; Hatfield/VRTC 2009). These data will help facilitate planned remediation efforts for Bien Hoa Airbase, which are currently being discussed between the Governments of Viet Nam, the United States, and the international community.

Dioxin (particularly 2,3,7,8-tetrachlorodibenzo-*p*-dioxin; also referred to as 2,3,7,8-TCDD or TCDD), a known component of the Agent Orange mixture, is known to cause an increased risk of cancers, immunodeficiencies, reproductive and developmental changes, nervous system, and other health problems. Dioxins in soil can pose a lingering threat to human health. Paustenbach *et al.* (1992) has indicated that the half-life of dioxins in subsurface soils can extend to 100 years. Once in the human body, the half-life is estimated at approximately 7 to 11 years.

Many western jurisdictions have taken a “standards/guideline” approach to protect human health from dioxin exposure. Numerical standards and guidelines addressing TCDD contamination have been established by many reputable organizations and scientists (e.g., WHO/EURO 1988, 1989, 1991, 1998a, 1998b, 2001, Agency for Toxic Substances and Disease Registry 1997, 1998; International Agency for Research on Cancer [a division of the World Health Organization] 1997). Standards have also recently been released for Viet Nam (National Standard TCVN 8183:2009). Mitigation action is recommended and/or enforced when these contamination guidelines are exceeded in soils, sediments, or human food.

Despite the fact that environmental and human impacts of dioxins have been known for a long time, it has only been in the recent years that adequate measures have been taken to properly assess the extent and impact of contamination around known hotspots in Viet Nam, especially in Bien Hoa, Da Nang, and Phu Cat. Protection of human health in the vicinity of these dioxin hotspots is of key concern, and Bien Hoa is a priority area for intervention, given its historical significance as the largest Ranch Hand site in Viet Nam. Clean up efforts are currently underway at Da Nang Airport, with US Government funding.

Primary conclusions from studies conducted at Bien Hoa Airbase and its vicinities between 2008 and 2010 are as follows:

- Elevated TCDD levels, a contaminant in Agent Orange, were detected in samples analyzed from the perimeters of the Bien Hoa Airbase in 2004 and 2005 (Hatfield/10-80 2006). The study identified two dioxin “hot” zones in Bien Hoa City at South Base Lake, Bien Hung Lake and vicinities, and near the eastern end of the runway. The maximum soil TEQ concentration recorded in 2006 was 425 ppt, from a sample collected southeast of the Airbase. The highest sediment dioxin was recorded at South Base Lake (797 ppt TCDD and 833 ppt TEQ); this sample exceeded the Vietnamese standard (150 ppt TEQ) by more than five (5) times. TCDD was over 92% of the TEQ in both samples, clearly indicating Agent Orange contamination.
- The Hatfield/VRTC (2009) study found several areas inside Bien Hoa Airbase which had dioxin levels above the internationally accepted standard of 1,000 ppt TCDD in soils; this included the Southwest Corner of the Airbase, Pacer Ivy Area near the runway, and Z1 Area and its vicinity. The maximum soil dioxin level was observed in a sample collected at a depth of 60-90 cm in the Z1 Area, which exhibited extremely high TEQ (262,000 ppt) and TCDD (259,000 ppt) concentrations. Samples collected from different depths at the same site all exhibited TEQ concentrations $\geq 26,400$ ppt (with over 91% TCDD). Highest sediment TEQ was detected in a lake sampled from the Pacer Ivy Area (5,870 ppt TCDD; 5,970 ppt TEQ).
- Building on previous studies, the current study extensively sampled areas inside and outside the Bien Hoa Airbase, including the Pacer Ivy Area, southwest corner of Airbase, Z1 Area, northeastern perimeter, northern perimeter and Bien Hoa City (south). The analytical chemistry undertaken at AXYS, a WHO-tested and approved dioxin laboratory, indicated elevated TCDD levels in all areas sampled on the Airbase. Highest contaminant levels were recorded in the Pacer Ivy Area; the maximum soil TCDD concentration was 61,400 ppt, with a resultant TEQ of 61,800 ppt. The most contaminated lake bottom sediments were also found in the Pacer Ivy area, with TEQ concentrations ranging from 32.1 to 2,020 ppt.
- As of 2010, dioxin continues to enter the aquatic ecosystem, the general environment, and the food chain. To this day, dioxin levels recorded in the Bien Hoa Airbase continue to exceed all international standards and guidelines for these toxic chemicals.
- Dioxin congener profiles confirm that the main source of dioxin contamination in the Bien Hoa Airbase area was Agent Orange and other dioxin-containing herbicides. TCDD contributed over 90% of the TEQ in soil and sediment samples collected from all areas inside the Airbase and outside in Bien Hoa City. A more detailed account of past site investigations and contaminant distributions is available in Hatfield/10-80 (2006) and Hatfield/VRTC (2009).

- Other contaminants (particularly 2,3,4,7,8-PCDF and 1,2,3,7,8-PCDD) also contribute to the total PCDD/PCDF load in some samples analyzed. Contaminants such as polychlorinated biphenyls, organochlorine pesticides and hydrocarbons are also likely present in the environment, both inside and outside the perimeter of Bien Hoa Airport. Other potential dioxin sources in Bien Hoa need to be determined and quantified in order to verify the total dioxin load to the environment and human population.
- The present study (and previous work by Hatfield/10-80/Office 33/VRTC [1998, 2000, 2003, 2006, 2007, 2009]) has verified that the highest concentrations of Agent Orange dioxin in soils/sediments in Viet Nam are found in the top 10 cm layer; some contamination is found in deeper strata (e.g., >60 cm) in Bien Hoa, but only limited to the former storage area in the Z1 Area (Hatfield/VRTC 2009). In this study, the depth profiles at Pacer Ivy Area indicated elevated TEQ levels in the 0-30 and 30-60 cm depths.
- The maximum TEQ value in Tilapia fat, 4,040 ppt (wet weight basis), was recorded in 'Mr. Hoc Lake' in the Pacer Ivy Area, which is more than 200 times the acceptable level established by Health Canada. Tilapia fat levels in 'Mr. Quy Lake' were 2,460 ppt TEQ (wet weight basis), which is more than 120 times the acceptable fish consumption level. High concentrations (more than 70 times the guideline) were also found in 'NE Perimeter Lake', 'Gate 2 Lake' and 'Z1 Lake'. It is likely other aquatic biota in these lakes (such as frogs, snails, ducks, etc.) are also contaminated.
- Tilapia fat tissues sampled from Bien Hoa Market and Gate 2 Market, where fishermen inside the Airbase sell their aquaculture products, exhibited low TEQ concentrations.
- Collectively, the concentrations of total dioxins and furans indicate extremely high contamination, and confirm the south, southwest and western parts of the Bien Hoa Airbase as significant PCDD/PCDF hotspots. The northern and eastern parts of the Airbase exhibit significantly lower dioxin contamination.
- The evidence indicates dioxin moves from the former storage sites in Pacer Ivy and Z1 Areas and into nearby watercourses, and ultimately into humans (via ingestion of contaminated fish and direct contact with soils and sediments), and is directly linked to historical Agent Orange use on the Airport.
- Soils throughout the Z1 Area have been placed in a contained landfill (43,000 m³) as a part of MND and GVN remediation efforts ongoing at the Airbase. GVN and MND's efforts have resulted in a reduction in dioxin contamination at the main hotspot area, but other hotspots remain on the Airbase.

- People who may regularly come into close contact with contaminated soils derived from the site may ingest small amounts of the soil through incidental hand-to-mouth activity. Given the notably high PCDD concentrations in soil, even small amounts of incidental soil ingestion can potentially cause significant exposure.
- Dermal absorption of PCDD may occur where certain people come into contact with contaminated soil or sediment during activities such as working on site, or wading into sediments while fishing, harvesting vegetation, etc. Soil or sediment contacting the skin for prolonged periods may result in small amounts of contaminants adhering and absorbing into the skin.
- Because contamination is generally found in surficial soil, finer contaminated particulates may on occasion become suspended in the air due to wind erosion or disturbance by cars and trucks. Airborne particulates carrying PCDDs may be inhaled and absorbed across the respiratory pathway. Although no airborne particulate data are presented in this report, inhalation of such particulates is likely a significant dioxin exposure pathway under periodic conditions.
- Given the high environmental levels of dioxin recorded in the southern and southwestern Airbase area, the human population of Bien Hoa City likely continues to be exposed to dioxin from contaminated food (especially fish), and also absorbs dioxin through the skin and lungs as a result of direct exposure to contaminated soils, sediments, and dust from the Airbase.
- The people most affected by direct exposure to dioxins from the Bien Hoa Airbase hotspots are those who fish and conduct aquaculture and agriculture from Z1 Lake, Pacer Ivy Lakes and other privately owned lakes and ponds inside the Airbase (and their extended families). Others may also be affected by eating fish and other aquatic animals harvested from the Airport lakes, although exact numbers are presently unknown.
- Human blood serum samples were collected and analysed for the first time in Bien Hoa during present study. Serum dioxin levels recorded in the 2010 study (n=42 blood donors sampled) for Bien Hoa Airbase workers ranged from 19.3 to 2,020 pg/g lipid basis. TEQ concentrations in all but one participant exceeded the WHO (1998) standard of 30 pg/g (equivalent to chronic intake of 4 pg/kg bw/d). Extremely high TEQ concentrations (1,080 - 2,020 pg/g TEQ) were found in three (3) individuals who actively harvest fish and plants from the Bien Hoa Airbase. Their dioxin levels were more than 35 times globally acceptable levels. These results support the contention that various people (either present on site or at peripheral locations), activities, and conditions coexist to create operative exposure pathways and potential for health risks.

- In analysing all individuals sampled for factors that could explain their blood dioxin levels, location of fishing was deemed a significant factor. A high variability in serum lipid values were discovered among individuals who consumed fish caught exclusively from inside the Airbase, and those who caught fish from both inside and outside the Airbase and solely from outside. No significant gender- and age-related effects on serum dioxin levels were identified.
- The typical range of TCDD in the general population of industrialized countries has been reported as 3 to 7 pg/g (lipid-based) (ATSDR 1998). ATSDR also indicated that TCDD in human blood rarely exceeds 10 pg/g and that typically, lower levels of this contaminant are recorded in less industrialized countries. All Bien Hoa Airbase workers sampled during the 2010 programs exhibited TCDD concentrations in blood greater than 10 pg/g. These include residents from Tan Phong Ward, inside the Airbase, and Trung Dung Ward (Bien Hoa City).
- Dioxins and furans were recorded in all breast milk samples analyzed in 2010 (N=22). Maximum levels were detected in a mother (age 29) breastfeeding her 2nd child (30.3 pg/g lipid basis TCDD), who previously consumed fish from Z1 Lake and 'Gate 2 Lake'. Average Daily Intake of breast milk per infant was calculated based on WHO/Euro (1989); Total TEQ ingested by infants ranged from 5 to 172 pg TEQ/kg bw/d.
- All breast milk samples analyzed exhibited TEQs exceeding the WHO Tolerable Daily Intake guideline of 4 pg TEQ/kg bw/d. High dioxin and furan levels in breast milk are cause for concern, and emphasize the need for raising awareness of potential contaminated food items originating from Bien Hoa Airbase.
- Comparison of Bien Hoa (2010) breast milk data to those recorded in Hatfield/Office 33 (2007, 2009) studies at Da Nang Airport indicate levels observed in Bien Hoa are generally lower than in Da Nang; ADIs in breast milk samples collected from in and around Da Nang Airport ranged from 23.4 to 2,320 pg TEQ/kg bw/d.

Recommendations:

- Planning and implementation of remediation measures, and clean-up of Bien Hoa Airbase, is urgently required to ensure protection of the local population from future exposure to dioxins from historical Agent Orange use at the site.
- Final remediation and clean-up efforts should focus on mitigating dioxin and furan contamination downstream of the Z1 Area and at the Pacer Ivy Area. Current remediation efforts have focused on the construction of drainage ditches and a secure onsite landfill in the Z1 Area. Final destruction of dioxin contaminated soils in the Z1 landfill will also be required in the future.

- Cultivation of Tilapia, other fish species and aquatic animals (e.g., ducks, molluscs, etc.) should be halted immediately. Investigation of potential dioxin contamination related to other agricultural activities (e.g., raising livestock) should be conducted.
- Other potential dioxin and furan contamination sources, particularly uncontrolled combustion and industrial emissions, should be identified, as well as potential contaminated materials which may be present at the Airbase.
- Awareness raising of dioxin exposure pathways (eating contaminated fish and other food items raised on Bien Hoa Airbase, exposure to contaminated soil and sediment, uncontrolled combustion, etc.) is required to help reduce dioxin loads in local Bien Hoa residents, especially nursing mothers.
- Other major dioxin hotspots in Viet Nam, particularly Da Nang and Phu Cat, also require remediation and clean-up, to protect local populations from continued exposure to Agent Orange and other herbicides used over 40 years ago during the US-Viet Nam war. Lessons learned from ongoing cleanup activities at Da Nang Airport (funded by the US and Vietnamese governments) will be invaluable for the future remediation of Bien Hoa and Phu Cat Airbases, and at other dioxin hotspots in Viet Nam.



Source: Hatfield Consultants

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